PB-236 668

THE USE OF COMPUTER PROGRAMS TO CALCULATE REGIONAL DOMESTIC SOLID WASTE TRANSPORT AND DISPOSAL COSTS AND TO ASSIGN SERVICE AREAS TO MULTIPLE DISPOSAL SITES

Paul L. Zepp

Regional Planning Council

Prepared for:

Environmental Protection Agency

November 1972

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NTIS

National Technical Information Service
U. S. DEPARTMENT OF COMMERCE

BIBLIOGRAPHIC DATA SHEET

1. Report No. BTL/RPC - 72/100

2\.

PB 236 668

4. Title and Subtitle The Use of Computer Programs to Calculate Regional Domestic Solid Waste Transport and Disposal Costs and to Assign Service Areas to Multiple Disposal Sites

5. Report Date November, 1972

6\.

7. Author(s) Paul L. Zepp

8. Performing Organization Rept. No.

9. Performing Organization Name and Address
Regional Planning Council
701 St. Paul Street
Baltimore, Maryland 21202

10. Project/Task/Work Unit No.

11. Contract/Grant No. G06-EC-00289-01

12. Sponsoring Organization Name and Address
Solid Waste Office
Environmental Protection Agency
401 M Street, S. W.
Washington, D. C. 20024

13. Type of Report & Period Covered

14. Final

15. Supplementary Notes

16. Abstracts

A computer program translating populations from zones to solid waste generated and allocating waste to disposal sites by means of a transportation program and giving minimum costs for disposal site patterns.

17. Key Words and Document Analysis. 17a. Descriptors

17b. Identifiers/Open-Ended Terms

Solid Waste (disposal transportation program cost analysis)

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

17c. COSATI Field/Group

18. Availability Statement Available to the public from the
National Technical Information Service
2285 Port Royal Road
Springfield, Virginia 22151

19. Security Class (This Report) UNCLASSIFIED

20. Security Class (This Page) UNCLASSIFIED

21. No of Pages 189

22. Price $12.50-2.25

FORM NTIS-35 (REV. 10-73) ENDORSED BY ANSI AND UNESCO. THIS FORM MAY BE REPRODUCED USCOMM-DC 8265-P74

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The preparation of this report was supported in part by a solid waste disposal grant from the Solid Waste Office of the Environmental Protection Agency (Grant No. G06-EC-00289-01).

TABLE OF CONTENTS

Page

LIST OF TABLES iii

LIST OF FIGURES iv

DICTIONARY OF SYMBOLS USED IN THE TRIPUT PROGRAM vi

Chapter

I. INTRODUCTION. 1

II. SUMMARY 5

III. GENERAL DESCRIPTION OF THE SOLID WASTE MODEL. 9

IV. EXISTING STATISTICAL DATA 17

V. THE SKIM TREE TAPE 21

VI. LIMITATIONS OF THE MODEL 23

VII. THE TRANSPORTATION INPUT PROGRAM "TRIPUT" 27

VIII. FLOW DIAGRAM FOR THE TRIPUT PROGRAM IN FORTRAN IV 33

IX. THE TRANSPORTATION LINEAR PROGRAM "MODI" SOLUTION METHOD 39

X. USING THE MODEL 45

XI. REFUSE GENERATION RATES ON TRUCK ROUTES IN THE BALTIMORE REGION. 57

XII. DETERMINATION OF LANDFILL CAPACITIES. 65

XIII. LANDFILL OPERATION COSTS IN THE BALTIMORE REGION. 67

XIV. REFUSE DISPOSAL TRANSFER STATION AND TRACTOR TRAILER HAUL COSTS. 89

XV. MODEL TEST RUNS USING VARIOUS DISPOSAL SITE LOCATIONS IN THE BALTIMORE REGION 93

BIBLIOGRAPHY 124

1-f

APPENDICES

Appendix Page

A UNIVAC 1108 EXEC 8 CONTROL STATEMENTS USED IN THE "TRIPUT" PROGRAM 126

B UNIVAC 1108 EXEC 8 CONTROL CARDS USED IN THE "TRANUV" PROGRAM 136

C PARTIAL CARD IMAGE LISTING OF THE OUTPUT OF THE TRIPUT AND THE INPUT TO THE TRANUV PROGRAM FROM THE SAMPLE PROBLEM 144

D THE FORTRAN IV SOURCE LANGUAGE LISTING OF THE TRIPUT AND TRANUV PROGRAMS AND THE SAMPLE PROBLEM OUTPUT 152

E DOCUMENTATION OF THE TRANSPORTATION PROBLEM FROM THE IBM 360 PROGRAM LIBRARY 172

LIST OF TABLES

TABLE		Page
1	Domestic Refuse Collection in Baltimore County	62-63
2	Domestic Refuse Collection in Baltimore City	64
3	Summary of Run No. 1 Baltimore County	100
4	Summary of Run No. 2 Baltimore County	101
5	Summary of Run No. 3 Baltimore County	102
6	Summary of Run No. 4 Baltimore City	104
7	Summary of Run No. 5 Baltimore City	106
8	Summary of Run No. 6 Baltimore City and Baltimore County	108-109
9	Summary of Run No. 7 Baltimore County	111
10	Summary of Run No. 8 Baltimore County	113
11	Summary of Run No. 9 Baltimore City and Baltimore County	115
12	Summary of Run No. 10 Baltimore City and Baltimore County . . .	117
13	Summary of Run No. 11 Baltimore City	119
14	Summary of Run No. 12 Baltimore City	121
15	Summary of Runs No. 13, 14 and 15, the Baltimore Region	122
16	Cost of all route Transportation and disposal of refuse, Runs 13, 14 and 15	123

LIST OF FIGURES

Figure | Page
1 TRANSPORTATION ZONES OF THE BALTIMORE REGION 13
2 FLOW CHART OF THE SOLID WASTE TRANSPORTATION COMPUTER MODEL 16
3 MATRIX SYMBOLIZATION OF THE TRANSPORTATION LINEAR PROGRAM MODI SOLUTION METHOD 41
4 FORMAT OF CARD INPUT TO THE TRIPUT PROGRAM, CARDS A TO E 47
5 FORMAT OF CARD INPUT TO THE TRIPUT PROGRAM, CARDS F TO I 48
6 FORMAT OF CARD IMAGE OUTPUT FROM TRIPUT AND INPUT TO TRANUV PROGRAM 50
7 BALTIMORE CITY AND BALTIMORE COUNTY DOMESTIC REFUSE GENERATION RATE, LINEAR SCALE 60
8 BALTIMORE CITY AND BALTIMORE COUNTY DOMESTIC REFUSE GENERATION RATE, SEMILOGARITHMIC SCALE 61
9 SANITARY LANDFILL OPERATION COST CURVE 87
10 REFUSE DISPOSAL TRANSFER STATION AND TRACTOR TRAILE HAUL COST ANALYSIS 91
11 LANDFILL SERVICE AREAS RUN NO. 1 BALTIMORE COUNTY 97
12 LANDFILL SERVICE AREAS RUN NO. 2 BALTIMORE COUNTY 98
13 LANDFILL SERVICE AREAS RUN NO. 3 BALTIMORE COUNTY 99
14 LANDFILL SERVICE AREAS RUN NO. 4 BALTIMORE CITY 103
15 LANDFILL SERVICE AREAS RUN NO. 5 BALTIMORE CITY 105
16 LANDFILL SERVICE AREAS RUN NO. 6 BALTIMORE CITY AND BALTIMORE COUNTY 107
17 LANDFILL SERVICE AREAS RUN NO. 7 BALTIMORE COUNTY 110
18 LANDFILL SERVICE AREAS RUN NO. 8 BALTIMORE COUNTY 112
19 LANDFILL SERVICE AREAS RUN NO. 9 BALTIMORE CITY AND BALTIMORE COUNTY 114
20 LANDFILL SERVICE AREAS RUN NO. 10 BALTIMORE CITY AND BALTIMORE COUNTY 116

LIST OF FIGURES
(con't)

Figure   Page

21 LANDFILL SERVICE AREAS RUN NO. 11 BALTIMORE CITY 118

22 LANDFILL SERVICE AREAS RUN NO. 12 BALTIMORE CITY 120

23 LANDFILL SERVICE AREAS RUN NO. 15 THE BALTIMORE REGION 124

24 TRIPUT PROGRAM BUNDLE FOR UNIVAC 1108 EXEC 8 SYSTEM 135

25 TRANUV PROGRAM BUNDLE FOR THE UNIVAC 1108 EXEC 8 SYSTEM 142

26 TRIPUT TRANUV TANDEM PROGRAM BUNDLE FOR THE UNIVAC 1108 EXEC 8 SYSTEM 143

27 (SAMPLE PROBLEM) COST OPTIMIZED REFUSE DISPOSAL SITE SERVICES AREAS 172

DICTIONARY OF SYMBOLS USED IN THE TRIPUT PROGRAM

AREA: NAREA (conversion to real numbers).

ACRES: NACRES (conversion to real numbers).

CAPLBS: The amount of refuse generated in pounds per capita per day.

CAPLF: The unused landfill capacity in tons for each site.

CIJ: NCIJ (integer to real number conversion).

CINC(): An array containing the costs per ton to dispose of refuse at each incinerator site.

COST1: The cost per ton of refuse at a landfill site due to land value.

COST2: The cost per ton to operate a landfill calculated from an equation expressed in fill rate per day (tons) vs. operation cost per ton.

COST3: The cost per ton of hauling refuse from a transportation zone centroid to the disposal site zone centroid.

COST4: The total cost in dollars per ton of hauling refuse from a transportation zone centroid to the disposal site, plus the cost of refuse disposal at the site.

CSTHR: The hourly charge for collection truck operation in dollars.

DRDPAY: The collection truck drivers pay in dollars per hour.

DSLIFE: The calculated life of the landfill assuming the filling rate to be constant over the life of the site.

HOURS: The computer calculated hours spent by the refuse disposal truck to haul from the given transportation zone to the zone of the disposal site.

IDTAPE: Storage location for the first field of each skim tree block. This field must be bypassed each time a block of skim tree times are read.

ITEN: The matrix row number divided by 10. This is used to generate a table showing the location of transportation zone numbers vs. matrix column and row numbers.

ITIME: The vehicle travel times in hundredths of a minute from a population zone to the centroid of another population zone.

J: The subscript number of the disposal site zone number array.

K: Array subscript and the matrix row number assigned by the computer.

LABORS: The number of laborers on the collection truck in addition to the driver.

LL: The total number of zones used in the solution divided by 10.

LTW: The internal program file designation into which the answers from TRIPUT output are stored. The file contains supplies, demands, and unit costs of transportation from disposal site zones to other region zones. The external file name is TDUMP.

M: The number of transportation zones in the new matrix, as counted by the computer.

MM: Index variable used to print zone vs. matrix number table.

MNTONS: Total tons per week delivered to a disposal site.

N: The number of disposal sites.

NAREA: The area of the population zone in acres.

NC: Centroid counting field.

NCDS: An array containing the centroid numbers of the disposal site zones. These numbers are generated by the computer by counting the transportation zone position from the beginning of the numbering system to the point of identification of the transportation zone, and adding the number of centroid zones, (the first 32), that are deleted.

NCENT: The total number of centroid zones on the skim tree tape. This is the total number of "travel times" in a skim tree block. It is the output from a transportation program that has been run on the Control Data computer. The program generates the times from each centroid (zone) to all other centroids for a given year. The centroid numbering is from 1 to 678 consecutively and continuously, whereas the transportation zones are numbered from 1 to 964, contain 646 zones and are not numbered continuously. This latter numbering system is not compatible with computer programming. The centroid numbering of zones is compatible with computer programming, but we do not wish to use zones from 1 to 32 and zones with zero population we wish to drop; therefore, the TRIPUT program generates a new numbering of zones for use in the transportation program TRANUV.

NCIJ: The total cost of transporting refuse from a population zone to the zone of the disposal site, plus the cost of operating the disposal site. Values are in integered dollars and cents per ton (undecimaled). This avoids the use of floating point arithmetic and is memory space saving.

NL: The number of disposal sites less one.

NN: Number table.

NPOP: The population of the transportation zone.

NPR: The computer number designating the printer.

NR: The computer number designating the card reader.

NSUM: The summation of tons of refuse generated in the region.

NSWICH: Switching variable used to control print loop.

NTONS: TONWK - an integer array containing the tons (TONWK) generated per week from each transportation zone in the matrix.

NVALS: Calculated tons of refuse per week delivered to a disposal site.

NZ: The maximum number of population zones in the region.

NZONE: The transportation zone number in which the disposal site is situated.

NZOPOS: An ordered list of the transportation zone numbers of the region.

PAYLBR: The hourly rate of pay of a laborer working on a refuse collection route.

PERCNT: The decimal fraction of the total refuse generated in the region delivered to a disposal site.

POP: NPOP (conversion to a real valued number).

POPMIN: The population necessary to generate a selected minimum weight of refuse per week.

REGT: The percentage of total refuse generated in the region being transported to a particular disposal site.

TKCAP: The average capacity of a refuse disposal truck in tons.

TONDAY: The tons per day of refuse delivered to a disposal site based on a 6 day week.

TONS: NTONS (conversion to real numbers).

TONSMN: MNTONS (conversion to real numbers).

TONWK: The amount of refuse generated from a population zone per week, in tons.

TRCST: The cost of collection truck operation per hour exclusive of the truck driver and the laborers.

TRANMAP: The assigned name of the assembled elements of the DISPOSE file used in the UNIVAC EXEC 8 control command $^{7}_{8}$MAP, a control card word.

TRANXQT: The assigned name of the absolute program assembled by the $^{7}_{8}$MAP command of the UNIVAC EXEC 8 control system. It is essentially the TRANUV program in machine language.

TRIPS: The number of trips per week a truck of a given capacity needs to transport the refuse generated in one week from a zone.

UNLOAD: The unloading time at the disposal site in hours.

V: NVALS (conversion from an integer to a real number).

VALS: NVALS (conversion to real numbers).

VLAND: The dollar per acre value of the disposal site land.

WTMIN: The minimum lbs. generated in a population zone per week. This enables zones with low population densities to be dropped out of the system. Zones with low densities may not have pick-up service, or it may be desirable to ignore low density zones to cut down the transportation matrix size, in order to be within the capacity of certain computer memories.

X: TONDAY/100

I. INTRODUCTION

The Baltimore Region (like much of the nation) is faced with a serious environmental pollution problem. The problem is that of proper solid waste disposal for some 2.2 million people who live in the region. Mismanagement and neglect have resulted in a situation that will require a great effort to correct. This effort has already begun but must receive increased emphasis and impetus.

Recent estimates for the Baltimore Region have indicated that the per capita production of domestic and commerical solid waste alone was of the order of 4.7 pounds per day in 1970. This amounts to a staggering 4,890 tons (9.7 million pounds) of garbage, refuse and trash being transported to disposal sites in the Baltimore Region daily. This quantity may be nearly doubled when other sources such as bulky items and industrial contributions are considered.

The Regional Planning Council during a survey in 1969 found several significant facts regarding solid wastes in the region including the following:

1. Of 32 disposal sites in the Region, essentially all were substandard in their operation and maintenance in one way or another.
2. Burning of the refuse was still practiced at most of the sites.
3. Scvenging was practiced at some level at nearly all of the disposal sites.
4. No adequate records were available from the landfill sites or the collection areas.

Furthermore, because of the unavailability of data and the reluctance by some to furnish information concerning the solid waste problem, there is little doubt that much more information will be needed for proper county and regional solid waste planning.

The collection of domestic refuse in a large metropolitan area involves many trucks collecting from diverse service areas of various population densities. The disposal sites are generally located where land was available at the time that the need occurred. Usually the most economical location for the disposal site is not available, so another site must be chosen. If more than one site is available, then the problem of which one is cheapest to acquire and operate arises. This is followed by the problem of what is the most economical service area, and what is a reasonable life to be expected for the disposal facility.

At the inception of a disposal system, only a few sites can be considered. Most possible locations for one reason or another cannot be considered practical. Of these few selected practical sites each will have a maximum available capacity to accept refuse, and in most cases the acres available will be limited. The capacity of each site may be determined by a land survey and a grading study. In detail this means that a survey of the property must be made describing it by metes and bounds. Then ground elevations must be taken of the undisturbed terrain along a grid pattern. From these data a plan is drawn showing initial and final proposed grades, and plotted cross sections from which the capacity of the landfill may be calculated. After the capacity of the site has been determined, the life of the landfill may be decided upon. There seems at present no definite criteria to follow in this respect. Establishing a short life say of a year, will require that other sites be almost immediately available. This puts a strain on public officials and does not allow a breathing spell between site acquistions. If the life is set too long, delay in development of future park land and the like, may cause adjacent land depreciation. At any rate no hard and fast rule may be used for the determination of the life of a landfill, but each location must be decided upon by local conditions. Usually a range of time representing a minimum and a maximum life will be acceptable. This may extend perhaps from 3 to 15 years. If this amount of flexibility exists, the life that results in the lowest cost can be chosen.

In a large metropolitan region even after all candidates for refuse disposal sites have been found, the determination of the service areas and acceptance rates of each disposal site involves massive calculation and advanced mathematical methods. This report will be devoted to a demonstration of how this can be done for a metropolitan region aided by statistics already accumulated and with the aid of digital computer. The basic areas used for study in this model are the transportation zones (sometimes referred to as population zones). These are generally very small zones in the more urban areas for which various projections, such as population and travel times, have been developed by the Regional Planning Council (RPC).

II. SUMMARY

The selection of solid waste disposal sites is restricted in many ways. Usually site locations where transportation costs are at a minimum are unavailable. The reasons for this are prior occupancy, zoning restrictions, high land costs, public unacceptability or higher priority for other planned uses. The ultimate choice of locations is usually reduced to a few involving different methods of transportation and disposal. Even after the number of possible sites has been reduced to a finite number, and the values of other input parameters are known, considerable calculation must be done to determine the total cost of transportation and disposal, and to delineate the service areas for each disposal site.

We attempt to solve this problem using a computer simulation technique (UNIVAC 1108 computer with an EXEC 8 control system). The input format allows for 40 sites and 646 population zones. The input data are derived from previously compiled planning statistics. Known unit costs are obtained from refuse disposal operation experience. Population in zones is translated by the computer into tons of refuse supplied. Incinerator and transfer station acceptance rates are established by design. Landfill acceptance rates are determined by their capacity and the selection of the sites's life. Disposal site acceptance rates are construed as demands. The computer calculates the unit transportation costs to the population zones of the disposal sites from all other population zones. These unit costs of disposal are calculated from various established input statistics and related functions.

After supplies, demands, and unit costs have been calculated and stored in a computer file, these same values are used as input to a operations research linear transportation program. It assigns tons of refuse from population zones to disposal sites, and totalizes transportation

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and disposal costs. The collective zone assignments to the disposal site represent the service area of the site. The computer program that solves the transportation program may be used for site selection in either the balanced mode or in the unbalanced mode. In the balanced mode the supplies and demands are equal. In the unbalanced mode one or more disposal sites may be assigned surplus capacity.

The problem solution is a simulation of a set of domestic collection routes and disposal sites, and the truck transportation system that moves the refuse from the collection routes to the final disposal location. On route collection costs are not included, because it is felt that they are not changed significantly by selection of the disposal site location, or the method of disposal.

The population zones used in the problem solution do not coincide with the actual truck collection routes. Every planning organization uses a set of zones, census tracts, or planning districts as a geographical base to which statistics are assigned. These statistics are costly to compile, but theycan be used as input to many kinds of studies. Complete statistics based upon the actual refuse collection routes do not exist. It has not been the practice to collect this information. If statistics did exist, and could be used as input to this problem, the technique of the solution method would not change, but there would be a better approximation of the real life situation.

Once a set of supplies, demands and units costs are determined for the input to the transportation linear program, the computer calculates the optimum costs and determines the service areas of each disposal site. The acceptance rate of an incinerator or a transfer station is fixed by the designed size. The sizes of these facilities are not only determined by economics, but also by political factors for which there are no known ways of evaluation. The refuse acceptance rate of a landfill and its cost of operation is determined by its size and its projected life. These parameters too are not determined solely by economics, but also by political factors.

Before the transportation problem can be solved for a landfill, its size and life must be established, and since no bottomless pits have yet been discovered, the life of the landfill must be finite. Therefore, new locations must continually be discovered.

If all of the input data to the computer were discrete and accurate, there could be no argument about the final cost figures. The accuracy of the final costs are only as good as the input data. At the present time there has not been developed an accurate method of estimating the refuse generation rate from a small population zone. The practice of estimating the capacity of a landfill is by "eye balling it". This method is subject to inaccuracies. It seldom occurs that the life of the landfill is established at the project's beginning, and operated in a manner to meet this final date. The operators are usually involved with so many other problems that not enough thought is given to meeting a projected termination date.

At present it appears that the technology of the calculation of transportation and disposal costs has advanced beyond the practice of data collection. The research done on this report emphasizes the need for additional programmed systems to compile data and calculate landfill disposal unit costs as well as transportation costs.

Mathematical modeling is cheaper than trial and error solutions in the field, but discovering functions that will transpose known data to unknown data is often difficult. Inaccuracies are developed when loosely simulated functions are used. One such inaccuracy occurs when average pounds per capita per day generation rates are used to calculate refuse tonnage from a population zone.

III. GENERAL DESCRIPTION OF THE SOLID WASTE MODEL

The purpose of the Solid Waste Transportation Computer Model is to determine the relative costs of different refuse disposal site patterns, to determine the optimum cost service area at each site, to assist in the determination of the life of the landfills, and to aid in the selection of the site configuration.

This is done by the use of two computer programs written in FORTRAN IV. The first has been called TRIPUT, and the second TRANUV. The TRANUV program is an existing program obtained from the IBM 360 library of programs. It solves what has been called the "Transportation Problem." The Transportation Problem was originally formulated to determine the amounts of a single commodity that should be shipped from a group of dispersed factories to a similarly dispersed group of warehouses. The demand of the warehouses, the supply of the factories and the costs per unit from and to each combination are known. The solution is a pattern of cost-optimized product distribution between factories and warehouses.

The solution of the Transportation Problem has been programmed on numerous computer makes and models. One program that was available was written for the IBM Model 360 computer. This was a satisfactory program, but the IBM 360 computer available at the University of Maryland Health Sciences Computer Center did not have a large enough memory to solve the solid wastes problems that arise for the Baltimore Region. As a result the program was altered, so that it could run on the UNIVAC 1108 computer which was also available at the University of Maryland Health Sciences Center. The changes made consisted of increasing the dimensioned array sizes, changing the card read input to FASTRAND magnetic file input,

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adding of printer output commands to give cost summaries for each disposal site, and causing transportation zone numbers to be printed opposite each matrix row number. These were minor alterations that did not affect the main solution of the problem. In order to adapt the IBM 360 Transportation Program to the solution of the regional refuse disposal problem, it was necessary to write another computer program to translate the available regional data into the same units and format as input of the Transportation Program (TRANUV). The data input for the TRANUV program is the matrix size (MxN), the supply and demand in tons, and a matrix of costs per ton of transportation and disposal between each supply and demand point. In the refuse disposal problem the points of supply are the transportation zone centroids, and the points of demand are the centroids of these population zones in which the disposal sites are situated.

The matrix row numbers are an ordered enumeration of the linear equations describing the possible distribution of refuse from the transportation zones to the disposal sites. They also represent a renumbering of the transportation zones composing the problem, allowing the computer to deal with a continuous numbering system, rather than a discontinuous one as represented by the transportation zone numbers.

In the TRIPUT program the population of each zone is read in and then translated into tons of refuse generated per week from each zone. The refuse generated by each zone is calculated separately. The cost of transporting refuse from the population zones to the disposal sites is calculated from the travel times from each population zone centroid to the disposal site zone centroid. The travel times are read by the TRIPUT program from the Skim Tree tape of the chosen design year. This tape (described in Section V) is a copy of the output of the Control Data Transportation package of programs that has been made compatible with UNIVAC 1108 FORTRAN IV.

In the design of the model the total transportation and landfill disposal cost consists of the cost of operating the collection trucks from the route end to the disposal site and return, the cost of operating the landfill, the cost of real estate and the cost of the site development. In the case of incineration all disposal costs are combined into one fixed cost per ton and to this is added the cost of operating the collection truck from the route and to the incinerator and return.

The cost of operating the landfill is determined in the TRIPUT program by substituting in an empirical equation (Fig. 9, Page 87). The cost of operation of low input landfills is greater per ton of refuse than large input landfills. The cost per ton to operate is a function of the landfill refuse acceptance rate.

The population zones with zero population and those generating less than one ton of refuse per week are dropped out of the solution of the problem. This must be so, because the mathematical method used to solve the Transportation Program does not permit any supply point to have zero units (tons), and because the TRANUV program is written only for integered values.

An ordered list of the numbers of the transportation zones are read into the TRIPUT program from cards. Because this list of numbers is not a continuous set, it is not compatible with efficient FORTRAN programming. It does not permit the easy use of the subscripting of variables. As a result the computer must be programmed to renumber the population zones, so that all numbers are continuous. Additional data consisting of population and areas used in the TRIPUT program are also read in from cards in the same order as the zone numbers.

The travel times on the Skim Tree tape are arranged in centroid order. This is done because the Control Data Corporation upon generating the Skim Tree data, found that it was necessary to assign a new set of continuous numbers in place of the transportation zone numbers to make the programming of the problem practical. In addition they were requested to add 32 more zones in the center of the region. The centroid numbering system that they assigned is continuous. Centroid number 33 corresponds to transportation zone number one, and there are 678 centroid zones instead of 646 as in the Transportation Zone numbering. The TRIPUT program reads population and areas from cards designated by transportation zone numbers, but travel times are read from magnetic tape identified by centroid numbers. Because of this incompatibility a new matrix number system must be assigned. The program does the zone number housekeeping and prints a table so that the transportation zones may be identified with the newly assigned computer matrix numbers. Consequently, each population zone has three numbers, the transportation zone number, the centroid number and a matrix number.

The TRIPUT program also prints a table that gives an orderly accounting of activity at the refuse disposal sites. It displays the acceptance rate of each site in tons per week in relation to the percent of the regional total, the disposal site cost per ton, the landfill site life, the value of the land per acre, and the remaining capacity of the landfill in total tons. Another table displays the truck costs, capacity, driver and labor costs, so that if the values are changed they may be identified with the computer run.

The TRIPUT program reads from cards the transportation zone number in which the disposal site is situated. The computer identifies the centroid associated with each zone, then searches the Skim Tree tape for the block of travel times associated with that centroid number. All travel times identified by centroid numbers in which there are no disposal sites are bypassed. Since the transportation zone numbers of the disposal sites are arranged in numerical order, only one pass through the tape is necessary.

When the total tons generated by each population zone and the total tons accepted by each disposal site are calculated and written into the FASTRAND file TDUMP, the printer signals the event by a line print showing the number of zones of supply (M) and the number of zones of demand (N). Each time that the computer calculates a block of costs associated with the demand of a disposal site, it writes the values also into the TDUMP file, and prints a line indicating that this has been accomplished. Each block contains the cost of transportation and disposal from all transportation

TRANSPORTATION ZONES

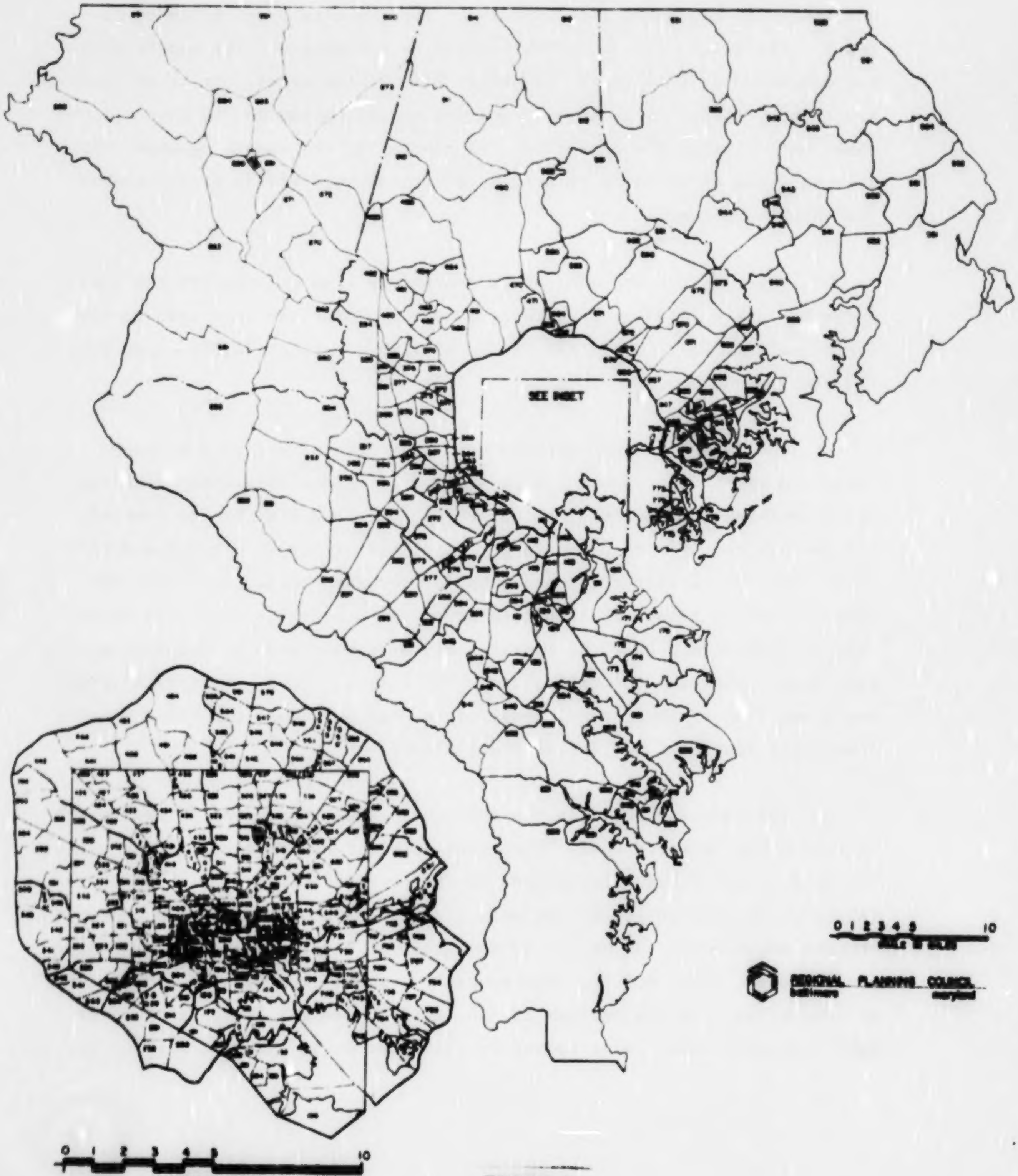
SEE INSET
0 1 2 3 4 5 10
SCALE IN MILES
REGIONAL PLANNING COUNCIL
baltimore maryland
0 1 2 3 4 5 10
SCALE IN MILES

FIGURE 1

zones retained in the problem to each particular disposal site.

After all disposal site demands, supplies and costs are calculated and stored in the TDUMP file, the input for the next program TRANUV is ready. The output of the TRIPUT program is voluminous. The sample problem described in this report generates 240 printed pages. It is not necessary to have a copy of these card images, so the option not to have all of these values printed was taken in the running of the sample problem. If necessary the data can be printed by a control card option at the end of the TRIPUT program.

The original Transportation program written for the IBM 360 computer was programmed for card input. If card input had been used in the solid waste model it would have been necessary to punch 13,224 cards for the sample problem.

The TRANUV program assigns tons of refuse generated from population zones to each disposal site while at the same time optimizing the total cost for the region. The printed output is a list of the tons of refuse supplied from each population zone, the unit cost per ton and the total cost of transportation and disposal for each zone. Two lists are created, one in transportation zone order and one in disposal site order Both of these lists show the matrix posit on number and the transportation zone number for easy identification. The listing, in disposal site order, has summations of total tons, total costs, and unit cost per ton for both transportation zones and for disposal sites.

The sample problem is run through the TRANUV program in what might be called the balanced mode. The total supplies and total demands are equal. The total tons of refuse generated by the population zones is equal to the total tons transported to the disposal sites. The program may also be run in an unbalanced mode. It may be advantageous to have an imbalance of demand over supply. This would be represented by excess capacity to accept refuse at some sites. If the program is run in this mode all excess tons of capacity greater than that supplied by the zones would automatically be assigned to a dummy origin which would have no physical meaning.* This might result in the elimination of some sites with high costs. Then, if some of the sites had higher disposal rates than they had previously, the site life in each case would be reduced.

---

*This is a mathematical technique inherent in the method of solution of the transportation problem. It should not be visualized as an actual movement of goods.

FLOW CHART OF THE SOLID WASTE
TRANSPORTATION COMPUTER
MODEL

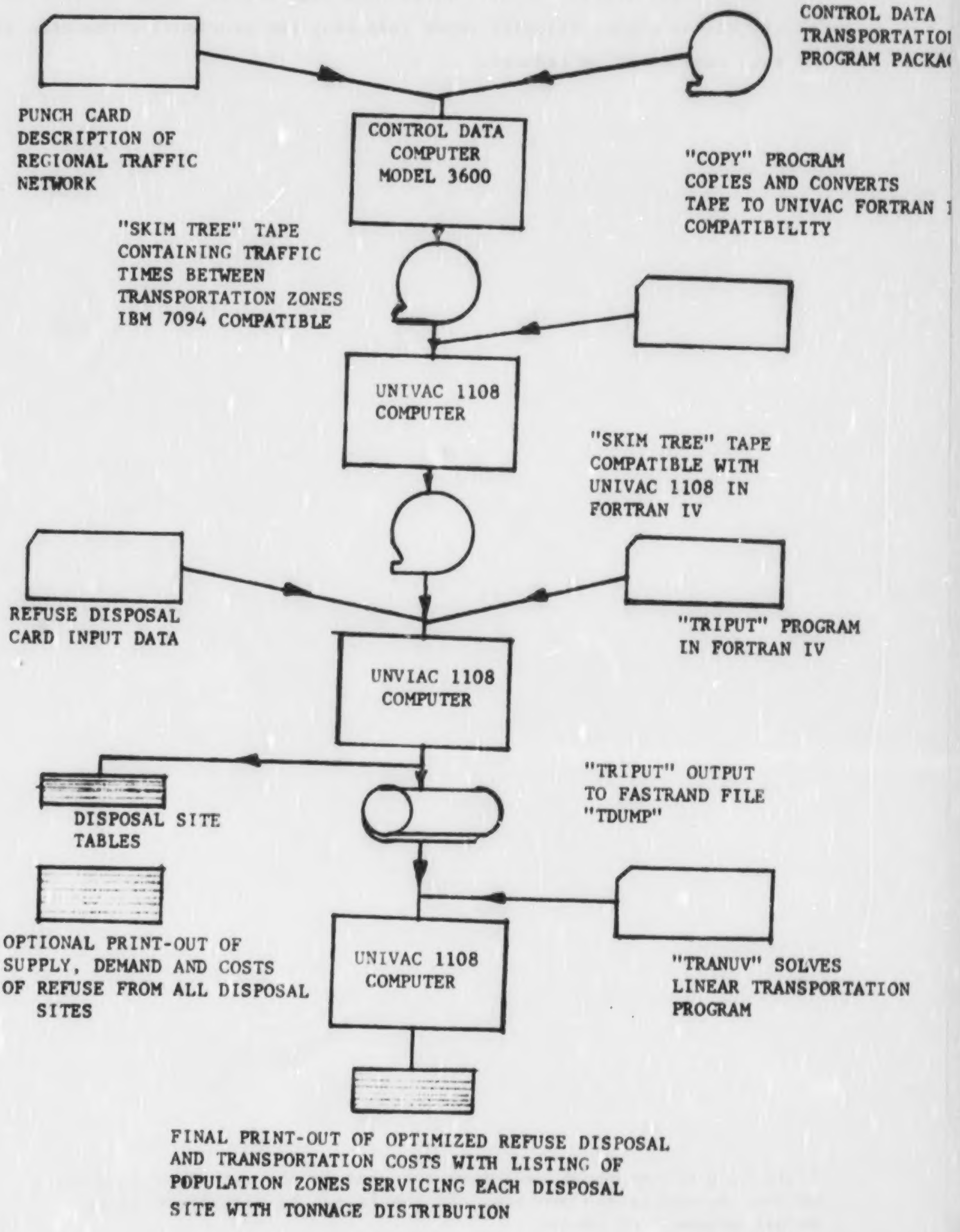
PUNCH CARD DESCRIPTION OF REGIONAL TRAFFIC NETWORK
CONTROL DATA TRANSPORTATIO
PROGRAM PACKA
CONTROL DATA COMPUTER MODEL 3600
"COPY" PROGRAM COPIES AND CONVERTS TAPE TO UNIVAC FORTRAN
COMPATIBILITY
"SKIM TREE" TAPE CONTAINING TRAFFIC TIMES BETWEEN TRANSPORTATION ZONES IBM 7094 COMPATIBLE
UNIVAC 1108 COMPUTER
"SKIM TREE" TAPE COMPATIBLE WITH UNIVAC 1108 IN FORTRAN IV
REFUSE DISPOSAL CARD INPUT DATA
"TRIPUT" PROGRAM IN FORTRAN IV
UNVIAC 1108 COMPUTER
"TRIPUT" OUTPUT TO FASTRAND FILE "TDUMP"
DISPOSAL SITE TABLES
OPTIONAL PRINT-OUT OF SUPPLY, DEMAND AND COSTS OF REFUSE FROM ALL DISPOSAL SITES
UNIVAC 1108 COMPUTER
"TRANUV" SOLVES LINEAR TRANSPORTATION PROGRAM
FINAL PRINT-OUT OF OPTIMIZED REFUSE DISPOSAL AND TRANSPORTATION COSTS WITH LISTING OF POPULATION ZONES SERVICING EACH DISPOSAL SITE WITH TONNAGE DISTRIBUTION

FIGURE 2

IV. EXISTING STATISTICAL DATA

The Regional Planning Council has been involved in a number of previous studies involving transit and highway systems. A normal procedure in any major transportation study is the division of the study area into smaller geographic units. These units, generally called transportation zones, are used for data collection and projection purposes. As a result of these studies the Baltimore region has been divided into 646 transportation zones. The zones are numbered so that the high order left hand digit represents the district and the low order right hand digits represent the zone number within the district. This method of numbering is not continuous, but leaves room for creating new or smaller zones within each district. The range of this numbering system is from zone 1 to zone 964 but the range contains only 646 zones.

The Baltimore Metropolitan Area Transportation Study, as well as other studies of traffic movement, has involved the development of transportation networks for each design year under study. Each design year is associated with a regional highway map showing all transportation links, nodes and speeds of travel for each link. The characteristics of each link in the system as well as the nodes at link intersections are assigned a set of parameters that simulate traffic conditions. These data are punched into IBM cards to serve as input to a group of computer programs that compile various pertinent statistical data necessary to planning activities. This computer service was not done by the Regional Planning Council but by the Control Data Corporation. They are the owners of these particular computer program systems used in the Regional Planning Council studies, (Control Data 3600 computer) and they will run the computer programs in any one of a number of modes to give selected outputs. Virtually all metropolitan areas in the United States have had similar studies conducted and, as a result, have been divided into some sort of zonal system suitable for use by this transportation model.

One of the modes of operation of the Control Data's Transportation Planning System is the compiling of a "Skim Tree". The Skim Tree option compiles and prints a matrix of travel times. The Skim Tree travel time from transportation zone to transportation zone is the sum of the minimum times for a motor vehicle to traverse each link of the Transportation network. The times are expressed in minutes. The factors governing the time are traffic lights, speed limits, stop signs, and the presence of other vehicles, however, it has been assumed that trucks and passenger cars will traverse the network at the same speed. These times are formatted in blocks. Each block of digital data contains a centroid ordered list of the shortest travel times from each transportation zone to all other transportation zones (Thirty-two centroids were added downtown). In the Baltimore Region this requires 678 blocks of 678 time values, or a total of 459,684 values.

The Regional Planning Council engaged the Control Data Corporation to run Skim Tree calculations for a number of design years. These calculations can be in the form of printed output or magnetic tape. The magnetic tape output is generally compatible with Control Data's 3600 computer, but the use of these data for other computer runs had made it necessary to also request magnetic tapes compatible with the IBM 7094. But these Skim Tree tapes are not compatible with FORTRAN IV input for the UNIVAC 1108 computer. To be able to use the UNIVAC 1108 computer for FORTRAN IV input, it has been necessary to write another program to make a duplicate copy of the IBM 7094 compatible tapes that can be read by the UNIVAC 1108 in FORTRAN IV language. This rather involved procedure is probably unique for the Baltimore Region and has been described only to indicate some of the problems involved in using the "Skim Tree" data. Each metropolitan area will have its own particular set of problems.

When the solid waste model was first conceived, it was expected that disposal costs and volumes could be obtained from local jurisdictions. It seemed reasonable to expect that the local solid waste organizations would have cost accounting systems from which unit costs and volumes could be determined. This assumption was found to be largely unjustified.

Baltimore City and Baltimore County have been the source of most of the refuse disposal data used for input in running the solid waste model. Baltimore County has had the best data available, but management has made changes in the disposal system and adequate records have not been kept of costs and volumes. The details of these changes become known only after the fact. Recently an agreement was made between a private commercial refuse collector for an exchange of refuse with the Baltimore County contractual domestic refuse collectors. The commerical refuse collector collects both in Baltimore City and Baltimore County. Under this agreement the Baltimore County collectors operating in the eastern part of the County are permitted to dump at the private landfill at Norris Farms and the collector's trucks are allowed to dump at Baltimore County's landfills at Reliable and Hernwood. The Norris Farm landfill is situated in the eastern section of Baltimore County next to the sewage disposal plant and on the south shore of Back River. The agreement allows a shorter haul for both Baltimore County collectors and the private collectors. By this agreement refuse collected in Baltimore City by the collector is hauled to landfills in Baltimore County, and refuse collected in eastern Baltimore County does not have to travel from Baltimore City to the County's Reliable landfill on the Patapsco River.

This is the same kind of disposal trade-off that the Regional Planning Council would recommend between Baltimore City and the surrounding counties, but for political reasons, it cannot be consummated. The reason given by the surrounding counties is that they do not want Baltimore City refuse to be dumped in their jurisdictions.

This situation cannot be simulated by the solid waste model because adequate records are not kept and basic costs cannot be calculated. Baltimore County does not know to which landfills the refuse collected by the private collector goes. The trade-off is not a balanced one. More tonnage is dumped by the private collector on county landfills than Baltimore County contractural collectors dump on the Norris Farm landfill. The capacity, costs and input rates are unobtainable. The owner is under no obligation to furnish this information. In reality Baltimore County is now operating a disposal system part public and part private, part domestic and part commercial. Most of the refuse comes from Baltimore County but somes comes from Baltimore City.

However, based on total refuse being received at certain disposal facilities, which is know, realistic actual costs of operation of disposal sites have been developed and incorporated in the model. In addition, costs of off-route transport of refuse have been calculated based on the model and compare very favorably with independent calculations carried out by Baltimore City and Baltimore County. These three independent calculations ranged from 48 to 52 cents a ton mile for off-route transportation. Land costs of disposal sites exclusive of debt service are also inherent in the model. Therefore based on these facts, it can be concluded that the model is very representative of real-life even though adequate data for total system costs is not available for comparison.

V. THE SKIM TREE TAPE

The use of the solid waste computer model is based upon the assumption that a Skim Tree tape of travel times has been created by a transportation study group. For those wishing to use the model in regions that have not had this service already performed, it will be necessary for potential model users to start fresh by either doing the job themselves or by obtaining the services of a transportation planning group.

The first step toward producing a Skim Tree tape is to acquire a highway system map with the following information: directions of traffic flow at intersections (one or two way), distances between intersections, and average vehicular speeds along links between intersections. With this information a link map can be prepared. The sections of highway between intersections are called links, and the intersections are called nodes. Information put on the link map describes the links and nodes, and the traffic coming into the nodes at the transportation zone centroids. Centroids, defining activity centers of the transportation zones, may be either origins or destinations and are put on the link map to completely describe the system.

In order to express the highway network characteristics conveniently and to identify them later a numbering system is used. The centroids of the transportation zones are numbered consecutively beginning with one and continued until all are labeled. Nodes are assigned another series of consecutive numbers.

When the network is defined, it is coded by identifying the terminals, the lengths and the travel speeds of each link. Then this coded data is punched on IBM cards. This is the input to the first program of the computer transportation package of programs, which builds the network. A following program of the package "skims the network" and thereby creates the "skim tree" tape. This latter program uses a minimum path algorithm that enables the computer to create travel times. Each of the travel times which make up a block is the shortest accumulated time from the designated transportation zone of that block to the centroid of any other transportation zone.

At this writing it is known that computer transportation packages are available for the IBM 7090, the IBM 360, and the Control Data 3600, but the output skim tree tapes from each of these machines must be recreated in order to be compatible for input to the UNIVAC 1108 in FORTRAN IV language. UNIVAC has a transportation package under development, but it is not yet available for use.

Wherever a transportation computer package of programs is available for the creation of skim trees, there is a manual available fully describing the function of the programs and the format of the input data.

VI. LIMITATIONS OF THE MODEL

The assignment of population to the transporation zones in the Baltimore Region was made from the U.S. Census for the year of 1960. Projections of population for other design years have been made based upon local and regional plans and development policies. Therefore, it must be admitted that these populations do not represent an actual recent head count, so there is a margin for error. The 1970 U.S. Census for the Baltimore Region has been published, but assignments to the transportation zones had not been made at the time that the computer runs described in this report were made.

The transportation zone sizes do not represent the geographical pattern of the refuse disposal truck routes. Some jurisdictions do keep records of the boundaries of the refuse truck routes, as well as house counts on the routes, but in other cases where private collectors are used, this information is the private property of the collector. These people are often suspicious of anyone wishing to obtain this information. Even where house counts on the routes are available, the number of persons occupying each house must be estimated from U.S. Census data. It is believed that the use of the transportation zones with their assigned population is a simulation as good as or better than any other available statistics.

The calculation of the travel times from transportation zone to transportation zone is done from a point within the transportation zone called the centroid. This point is a coordinated spot within the zone that is spoken of as the "center of activity". This point has been "eye balled in", therefore, it cannot be stated that this assumption is the epitome of precision. In addition to these assumptions, the refuse disposal site within its transportation zone has been assumed to be at the centroid of the zone. This assumption is necessary because the Skim Tree travel times are all from centriod to centroid.

The size of the transportation zones in some cases is small and allows all the precision that is needed. In other cases but only in rural areas, the size is too large. In the latter case this contributes to a more approximate solution. If a new set of data was to be collected with the sole purpose of using it in the solution of the refuse disposal transportation problem, these deficiencies could be corrected at the outset of the data assembly.

The refuse generated from each population zone is assumed to be the average of lbs. per capita per day calculated from truck routes in the Baltimore Region where the most reliable statistics are available. So far there is no known available statistic that can be correlated with the refuse generation rate to enable a function to be constructed that would give a prediction of the lbs. per capita per day on each truck route.

The curve of landfill operation costs constructed from a study of costs in the Baltimore Region is not linear. It therefore introduces a non-linear element into the unbalanced mode of the solution of the transportation problem. Therefore, the assumption of linearity is not totally valid. This may be circumvented by rerunning both programs of the model using the tons distribution obtained from the unbalanced run, and rerunning the TRANUV program in a balanced mode. But where the distributed excesses to the disposal sites are small, the second solution may not be noticeably different.

When the travel times from transportation zone to transportation zone for vehicles are calculated, different travel times may be obtained at different times of day. Further, passenger automobiles and trucks have different rates of travel. Then again, the personality of the truck driver may be a factor entering the travel time formula. However, average factors must be assumed to avoid a multitude of similar, but different solutions.

In the calculation of the costs of the transportation between population zones and the disposal sites, the cost of labor, the cost of truck operation, and the tonnage carrying capacity of the disposal collection trucks are considered to be the same for all trucks during a problem solution run.

VII. THE TRANSPORTATION INPUT PROGRAM "TRIPUT"

The function of the TRIPUT program is to convert transportation zone population, vehicular travel times and other data into refuse generation rates, disposal costs and transportation costs, and to put them into a format compatible with the input to the linear Transportation Program TRANUV.

At the beginning of the program some of the DIMENSION statements are used to assign storage for the input data read in from cards and tape. Other statements are used to assign storage locations in the computer for intermediate answers before they are permanently stored in the FASTRAND file for use in the following TRANUV program. The large capacity DIMENSION statements are sized for 647 words, the total number of transportation zones in the Baltimore Region plus one. The smaller sized DIMENSION statements are sized for 40 words, the maximum number of disposal sites. The DIMENSION sizes for the sites could be made larger to accomodate more sites since there is plenty of unused storage in the TRIPUT program. The following TRANUV program takes up more storage space, so that even though the TRIPUT program could accept a larger number of transportation zones and disposal sites, the matrix size is controlled by the TRANUV program.

The UNIVAC 1108 at the University of Maryland has a memory capacity of 132,000 words but an undetermined amount of this storage is used to store utility programs. The University System people state that for best efficiency no more than 32,000 words of program space should be used. The TRIPUT program uses 11,433 words of the computer memory and the TRANUV program which follows it uses 41,208 words.

Line 7 to 12 of the source program contain programming and problem constants. The IDTAPE variable is a location used to dump the tape

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identification symbol used by the original incompatible Skim Tree tape. It is not needed when reading the new tape in FORTRAN. Lines 8 to 10 are input or output device numbers, and lines 11 to 12 are maximum array sizes. All of these terms are defined in the model dictionary.

The data cards are read into the computer by the read instructions on Lines 13 to 29. Description of the data card format may be found in the section entitled "Using the Model."

The equation for the cost per hour of the disposal trucks is on line 37. The components of the equation are made of previously declared constants, read into the computer from data card A. (See Figure 4). This allows control of variables that contribute to the total truck cost.

The value of UNLOAD, read in from Card A has been fixed at .2 hours in the sample program. This was put in as truck unloading time at the disposal site. The assumption has been made that this is the same at at all sites.

The value of WTMIN, also read in from Card A, has been set at 2,000 lbs. All refuse generated less than this amount per week from a population zone causes that zone to be dropped out of the program solution. Statements on lines 31 to 39 result in the printout of the truck information, so that it may be identified with the computer run. Statements on lines 13 to 29 cause data to be read into the DIMENSION statements from the data cards A to I.

On line 42 is initiated a DO statement extending to statement 40 on line 58. In this loop the zone population is translated into tons of refuse generated per week. The population of a zone necessary to generate one ton of refuse is calculated, and an IF statement following causes all zones with less population than this to be dropped from the problem solution. At the top of the loop on line 43 an IF statement identifies the transportation zone of the disposal site. When identification occurs the next sequential statement on line 44 calculates the centroid number of the disposal site and stores it in the array NCOS. Thus an array containing the centroid numbers of all the disposal sites is constructed for later use in the program when the vehicular times must be read from magnetic tape. The disposal sites are identified by their centroid numbers.

Within the above DO loop at line 54, statement 30, a count is made of the transportation zones retained in the problem. This is also an assignment of a new set of numbers for the transportation zones called matrix numbers. Following on line 57 a running total of tons generated from all matrix numbered zones is calculated. When the computer exits from the loop on count NZ, the total tons generated from the region from all zones is retained by the MNTONS variable. This is the total supply.

The DO loop starting on line 67 and the statement following its ending on line 71 calculates the distribution of refuse to all sites. All disposal site demands except the last one are calculated by multiplying the sites decimal percentages of the whole by the total supply. The demand of the last site is obtained by subtracting the sum of N-1 sites from the total. This method guarantees that the sum of all demands and supplies will be exactly equal. Rounding off could otherwise produce an inequality. The supply calculations are then followed by a write statement on line 72. This statement puts the site demands into the TDUMP (LTW) file in the input format required by the TRANUV program. This operation is verified by the printing of a statement and the value of N. The TRIPUT program creates a balanced supply and demand input to the TRANUV program that is necessary for a balanced transportation problem solution. If it is desired to run the transportation program in the unbalanced mode, it is necessary to change (surplus) the supply values by writing an EDIT command after the supplies have been put into the TDUMP file. This must be done before the TRANUV program is run (See Section X).

The DO loop starting on line 75 and ending at statement 120 on line 91, calculates the cost of operating the landfills and the site life of each. The lives of all landfills, even those used to deposit incinerator ash, are calculated simply by dividing the landfill's remaining tons capacity by the refuse acceptance rate (demands) per week in tons times 52 weeks in the year. The cost attributed to the real estate value of the landfill is calculated by multiplying the land cost per acre times the total unfilled acres remaining and dividing by the tons of landfill capacity remaining. This is COST1 in dollars per ton of refuse.

The landfill's operation cost (COST2) may be calculated by an empirical equation illustrated in Fig. 9, if date can be obtained to construct an equation. The cost per ton to operate the site is assumed to be a function of the daily refuse input. This is determined by dividing the weekly input by 6, the number of days worked per week. COST1 and COST2 are added and stored in the array COST4 to be available for addition to the transportation costs that are calculated later in the program.

One line 78 within the above described DO loop an IF statement test for a 99. cost per acre value stored in the array VLAND and read from data card set D. The 99. is a means invented to identify a disposal site with a fixed cost per ton for disposal. Fixed cost disposal sites are generally characterized by incinerators and transfer stations in this model. When a fixed cost is encountered at a disposal site, the landfill calculations are bypassed and the fixed cost value from the array CINC (read from data Card B) is substituted for COST2, and COST1 is set to zero (see line 88 and 89).

Beginning at line 93 and ending with statement 190 on line 121, there are dual DO loops, a loop within a loop. The outside loop reads the Skim Tree tape and counts the blocks of vehicular travel times by their centroid numbers stored in variable NC. Each time that a block of travel times is read from the Skim Tree tape, the centroid number is compared with the centroid number of the disposal sites stored in the array NCDS. This is done by the IF statement on line 94. When a block of travel times on the tape is encountered whose centroid number matches the centroid number of the disposal site, a branch to the start of the inside loop at line 99 occurs. At this occurrence vehicular block times associated with the disposal site have been read into the array ITIME. This is a block of storage locations reserved inside the memory of the computer.

When a match of centroid numbers does not occur, the computer goes back to the tape read statement 145 on line 95 and reads another block of times, and continues doing this until a match does occur.

The DO statement beginning on line 99 ranges from matrix row number 1 to NZ. NZ is the maximum number of transportation zones in the region. A test for zero population is made by the IF statement on line 101, enabling the computer to save time by avoiding unnecessary calculations. The tons generated per week is calculated on line 102, followed by the calculation of the minimum population necessary to generate one ton per week. The following IF statement on line 104 bypasses all zones generating less than one ton per week.

On line 106 the truck trips necessary to move the refuse from each transportation zone to the disposal site are calculated. The number of trips is determined by dividing the tons per week by the tons per truck capacity, and since the truck must make a return trip this is multiplied by 2.

On line 107 the truck hours per week for the zone is calculated by multiplying the number of trips by the travel time between the transportation zone and the disposal site. The travel times from the Skim Tree tape are in units of hundredths of a minute expressed in blocks of 5 integers. To convert to hours the product of TRIPS X ITIME must be divided by 100 and by 60 to give hours of time. Then to this time is added the unloading time.

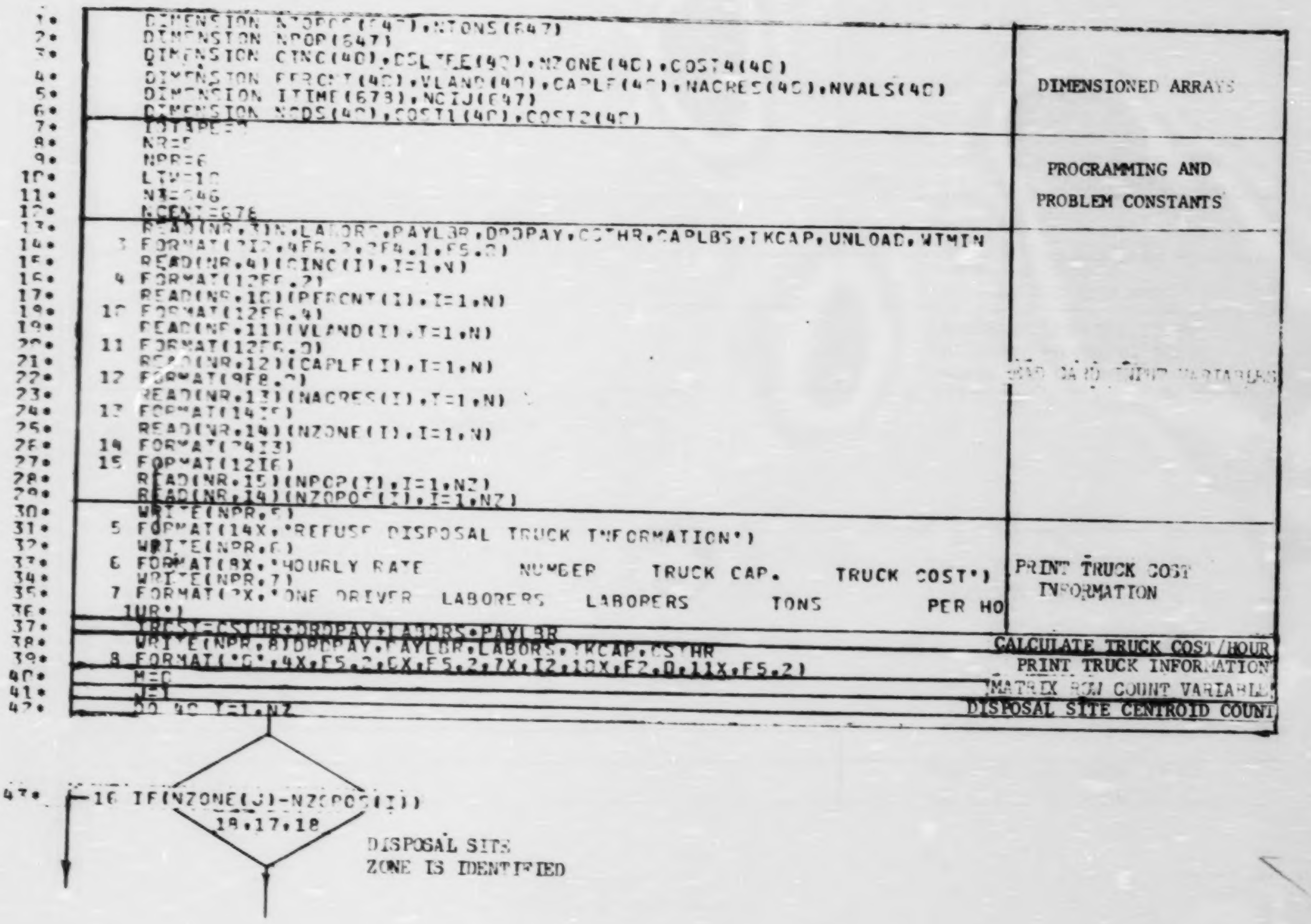
The total cost to operate the truck per ton of refuse is calculated on line 108 by multiplying the truck cost per hour by the total hours divided by the tons of refuse generated from each transportation zone.

All three landfill costs at this point in the program have been calculated, the land value cost per ton, COST1; the cost to operate the landfill, COST2; and the cost of transportation, COST3. On line 109 these are added together into a composite cost per ton, CIJ and on the following line 110, this value is put into array NCIJ in the form of dollars and cents per ton, but integered (without a decimal point). This is the necessary format for costs per ton for the input to the TRANUV program. Each time that an NCIJ cost is calculated from a zone to a disposal site a count is made (see line 111). This K value is used as the subscript to the NCIJ array. When all zone costs are calculated for disposal site there is an exit from the DO loop. On the next sequential statement after the CONTINUE on line 113 a block of costs for a disposal site is written into the FASTRAND file, TDUMP, and the site number and its centroid number are identified by a written line on the printer. The CONTINUE statement 190 on line 121 is the termination of the outside DO loop started on line 93. The computer makes one pass thru the loop for each disposal site. When the costs for all disposal sites have been calculated there is an exit. At this point in the program all input values have been calculated for the TRANUV program, demand, supply and transportation costs.

In order to be able to identify the matrix numbers with the transportation zone numbers, the ordered list of retained transportation zone (NZOPOS) numbers used in the TRIPUT program are read into the TDUMP file after the problem data. These transportation zone numbers are printed out in a parallel column when the final answers from the following program (TRANUV) are printed. All of the data input for the TRANUV program has at this point been stored into the TDUMP file, and the file is terminated by an END OF FILE statement.

The remainder of the TRIPUT program is devoted to printing out tables needed to identify the problem. The first table is the disposal site data, some of which is input to the problem and some of which is calculated. The second table is for the purpose of translating the problem zone matrix numbers into transportation zone numbers, and to show which transportation zones are used in the problem and which have been dropped because of zero population or because less than one ton of refuse per week was generated from the zone.

FLOW DIAGRAM FOR TRIPUT PROGRAM
IN FORTRAN IV



```
      DIMENSION NZOPOS(647),NTONS(647)
      DIMENSION NPOP(647)
      DIMENSION CINC(40),DSLFEE(40),NZONE(40),COST4(40)
      DIMENSION PERCNT(40),VLAND(40),CAPLF(40),NACRES(40),NVALS(40)
      DIMENSION ITIME(673),NCIJ(647)
      DIMENSION NCDS(40),COST1(40),COST2(40)
      INTAPE=7
      NR=5
      NPR=6
      LTV=10
      NZ=646
      NCENT=676
      READ(NR,3)N,LABORS,PAYLBR,DRDPAY,CSTHR,CAPLBS,TKCAP,UNLOAD,WTMIN
    3 FORMAT(2I2,4F6.2,2F4.1,F5.2)
      READ(NR,4)(CINC(I),I=1,N)
    4 FORMAT(12F6.2)
      READ(NR,10)(PERCNT(I),I=1,N)
   10 FORMAT(12F6.4)
      READ(NR,11)(VLAND(I),I=1,N)
   11 FORMAT(12F6.0)
      READ(NR,12)(CAPLF(I),I=1,N)
   12 FORMAT(9F8.0)
      READ(NR,13)(NACRES(I),I=1,N)
   13 FORMAT(14I5)
      READ(NR,14)(NZONE(I),I=1,N)
   14 FORMAT(24I3)
   15 FORMAT(12I6)
      READ(NR,15)(NPOP(I),I=1,NZ)
      READ(NR,14)(NZOPOS(I),I=1,NZ)
      WRITE(NPR,5)
    5 FORMAT(14X,'REFUSE DISPOSAL TRUCK INFORMATION')
      WRITE(NPR,6)
    6 FORMAT(8X,'HOURLY RATE        NUMBER    TRUCK CAP.    TRUCK COST')
      WRITE(NPR,7)
    7 FORMAT(2X,'ONE DRIVER  LABORERS   LABORERS      TONS         PER HO
     1UR')
      TRCST=CSTHR+DRDPAY+LABORS*PAYLBR
      WRITE(NPR,8)DRDPAY,PAYLBR,LABORS,TKCAP,CSTHR
    8 FORMAT('0',4X,F5.2,6X,F5.2,7X,I2,10X,F2.0,11X,F5.2)
      M=0
      J=1
      DO 40 I=1,NZ
   16 IF(NZONE(J)-NZOPOS(I))
      18,17,18
```

DIMENSIONED ARRAYS
PROGRAMMING AND PROBLEM CONSTANTS
READ CARD INPUT VARIABLES
PRINT TRUCK COST INFORMATION
CALCULATE TRUCK COST/HOUR
PRINT TRUCK INFORMATION
MATRIX ROW COUNT VARIABLE
DISPOSAL SITE CENTROID COUNT
DISPOSAL SITE ZONE IS IDENTIFIED

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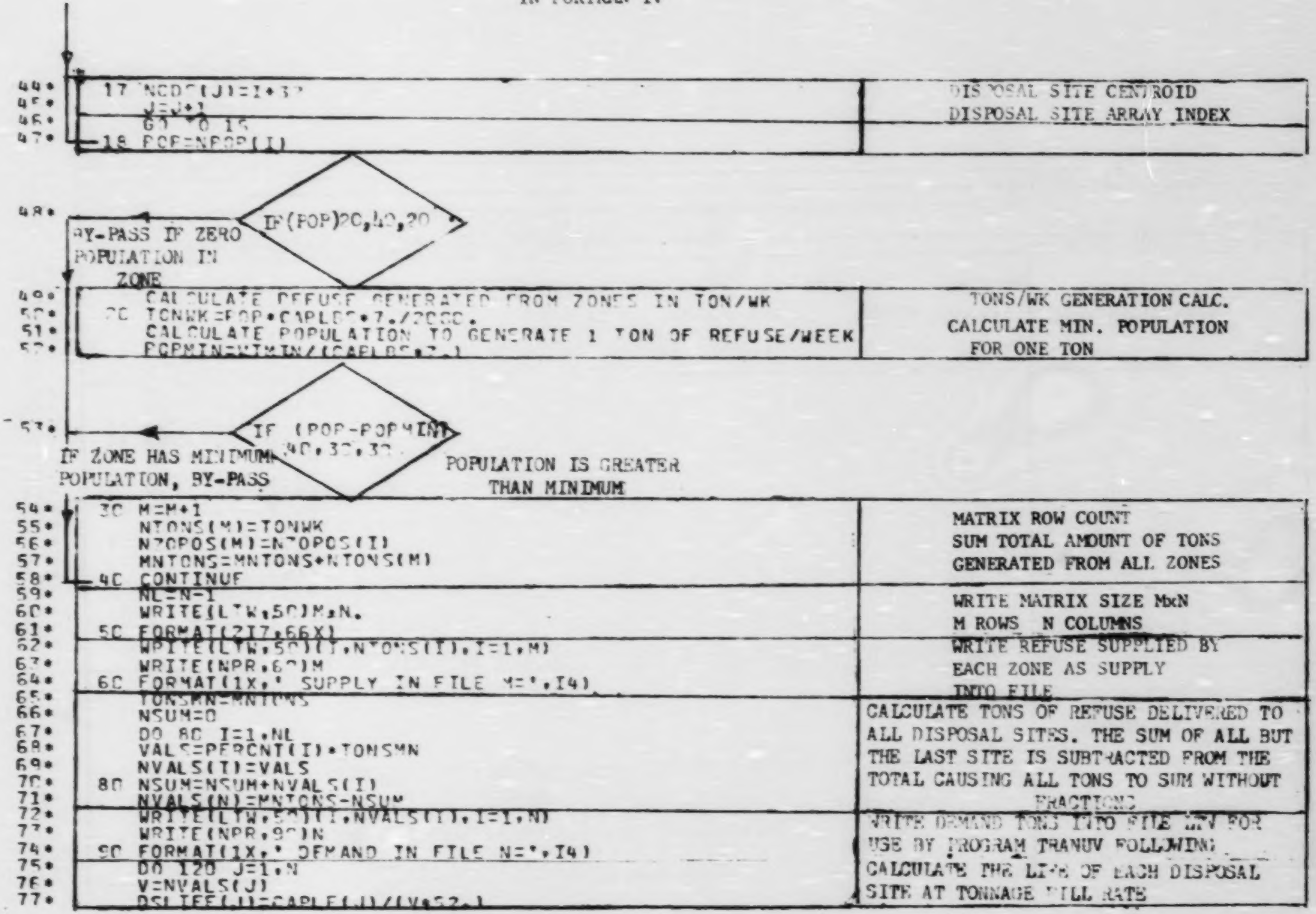
FLOW DIAGRAM FOR TRIPUT PROGRAM
IN FORTRAN IV


BY-PASS IF ZERO POPULATION IN ZONE
IF ZONE HAS MINIMUM POPULATION, BY-PASS
POPULATION IS GREATER THAN MINIMUM

```
   17 NCDS(J)=I+32
      J=J+1
      GO TO 15
   18 POP=NPOP(I)
      IF(POP)20,40,20
      CALCULATE REFUSE GENERATED FROM ZONES IN TON/WK
   20 TONWK=POP*CAPLBS*7./2000.
      CALCULATE POPULATION TO GENERATE 1 TON OF REFUSE/WEEK
      POPMIN=XIMIN/(CAPLBS*7.)
      IF (POP-POPMIN)40,30,30
   30 M=M+1
      NTONS(M)=TONWK
      NZOPOS(M)=NTOPOS(I)
      MNTONS=MNTONS+NTONS(M)
   40 CONTINUE
      NL=N-1
      WRITE(LTW,50)M,N.
   50 FORMAT(2I7,66X)
      WRITE(LTW,50)(I,NTONS(I),I=1,M)
      WRITE(NPR,60)M
   60 FORMAT(1X,' SUPPLY IN FILE M=',I4)
      TONSMN=MNTONS
      NSUM=0
      DO 80 I=1,NL
      VALS=PERCNT(I)*TONSMN
      NVALS(I)=VALS
   80 NSUM=NSUM+NVALS(I)
      NVALS(N)=MNTONS-NSUM
      WRITE(LTW,50)(I,NVALS(I),I=1,N)
      WRITE(NPR,90)N
   90 FORMAT(1X,' DEMAND IN FILE N=',I4)
      DO 120 J=1,N
      V=NVALS(J)
      DSLIFE(J)=CAPLE(J)/(V*52.)
```

DISPOSAL SITE CENTROID
DISPOSAL SITE ARRAY INDEX

TONS/WK GENERATION CALC.
CALCULATE MIN. POPULATION FOR ONE TON

MATRIX ROW COUNT
SUM TOTAL AMOUNT OF TONS GENERATED FROM ALL ZONES

WRITE MATRIX SIZE MxN
M ROWS N COLUMNS

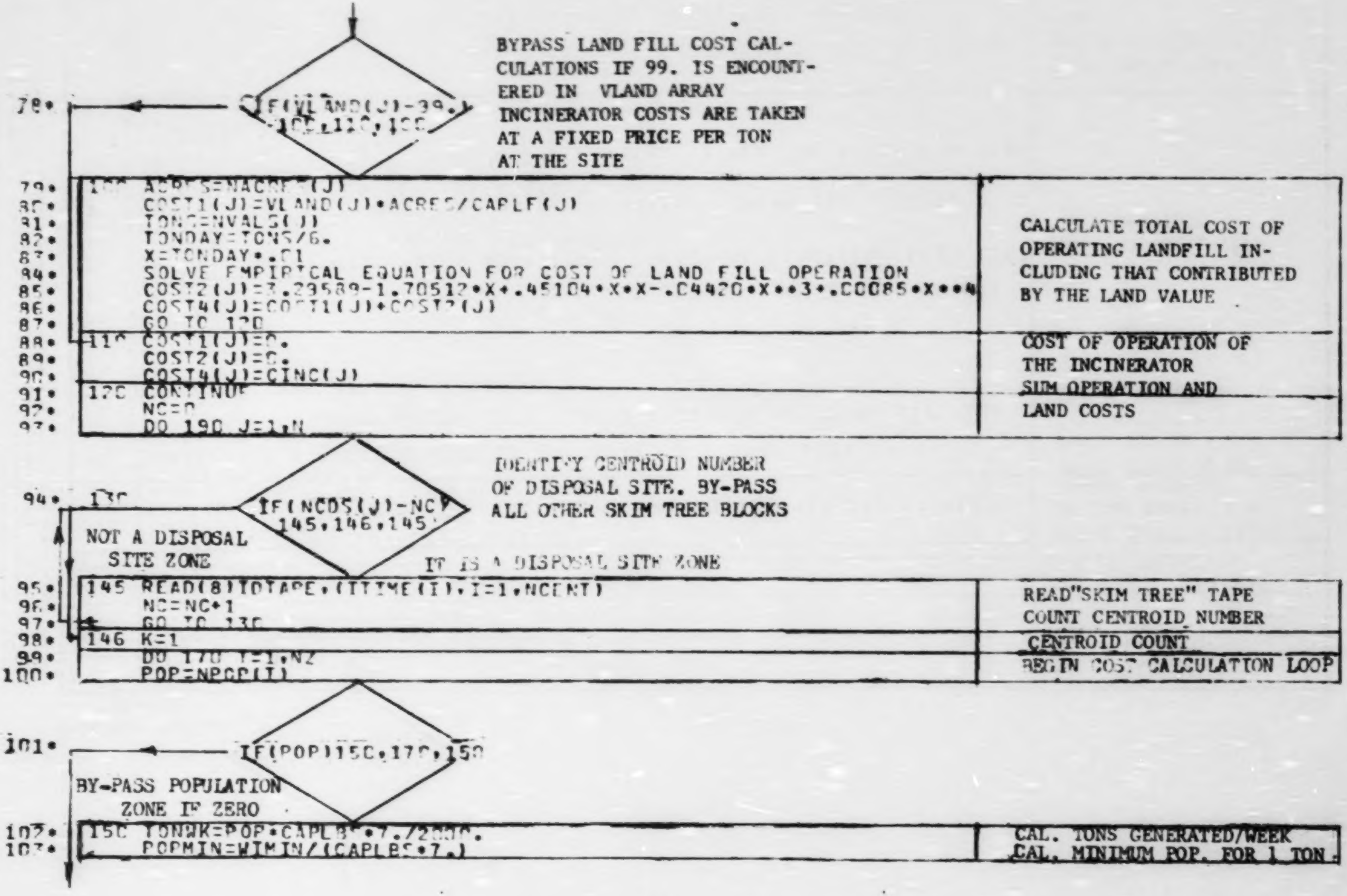
WRITE REFUSE SUPPLIED BY EACH ZONE AS SUPPLY INTO FILE

CALCULATE TONS OF REFUSE DELIVERED TO ALL DISPOSAL SITES. THE SUM OF ALL BUT THE LAST SITE IS SUBTRACTED FROM THE TOTAL CAUSING ALL TONS TO SUM WITHOUT FRACTIONS

WRITE DEMAND TONS INTO FILE LTW FOR USE BY PROGRAM TRANUV FOLLOWING

CALCULATE THE LIFE OF EACH DISPOSAL SITE AT TONNAGE FILL RATE

FLOW DIAGRAM FOR TRIPUT PROGRAM
IN FORTRAN IV



```
      IF(VLAND(J)-99.)100,110,100
  100 ACRES=NACRES(J)
      COST1(J)=VLAND(J)*ACRES/CAPLF(J)
      TONS=NVALS(J)
      TONDAY=TONS/6.
      X=TONDAY*.01
      SOLVE EMPIRICAL EQUATION FOR COST OF LAND FILL OPERATION
      COST2(J)=3.23589-1.70512*X+.45104*X*X-.04420*X**3+.00085*X**4
      COST4(J)=COST1(J)+COST2(J)
      GO TO 120
  110 COST1(J)=0.
      COST2(J)=0.
      COST4(J)=CINC(J)
  120 CONTINUE
      NC=0
      DO 190 J=1,N
  130 IF(NCDS(J)-NC)145,146,145
  145 READ(8)IDTAPE,(ITIME(I),I=1,NCENT)
      NC=NC+1
      GO TO 130
  146 K=1
      DO 170 I=1,NZ
      POP=NPOP(I)
      IF(POP)150,170,150
  150 TONWK=POP*CAPLBS*7./2000.
      POPMIN=WIMIN/(CAPLBS*7.)
```

BYPASS LAND FILL COST CALCULATIONS IF 99. IS ENCOUNTERED IN VLAND ARRAY INCINERATOR COSTS ARE TAKEN AT A FIXED PRICE PER TON AT THE SITE

CALCULATE TOTAL COST OF OPERATING LANDFILL INCLUDING THAT CONTRIBUTED BY THE LAND VALUE

COST OF OPERATION OF THE INCINERATOR

SUM OPERATION AND LAND COSTS

IDENTIFY CENTROID NUMBER OF DISPOSAL SITE. BY-PASS ALL OTHER SKIM TREE BLOCKS

NOT A DISPOSAL SITE ZONE

IT IS A DISPOSAL SITE ZONE

READ "SKIM TREE" TAPE

COUNT CENTROID NUMBER

CENTROID COUNT

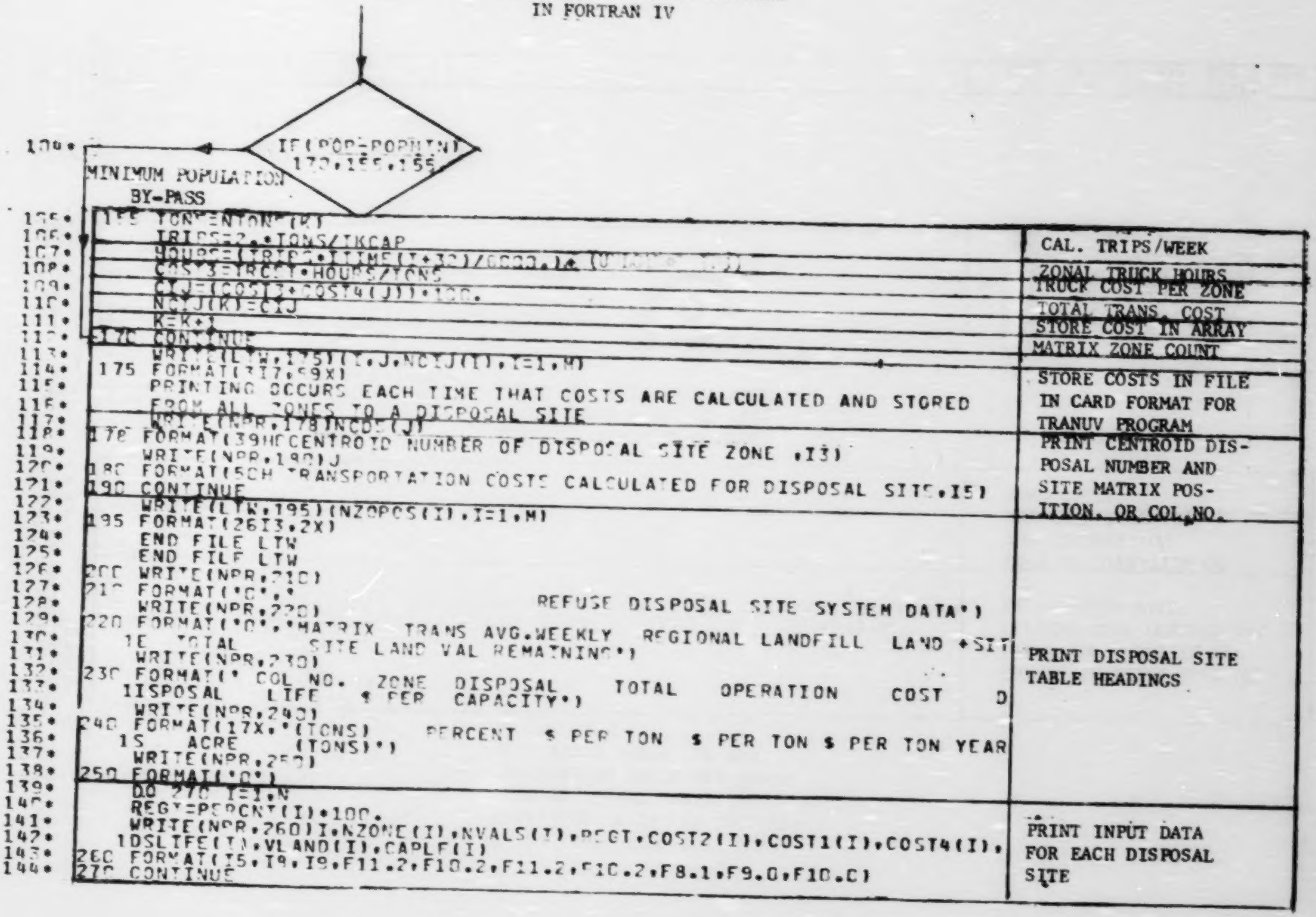
BEGIN COST CALCULATION LOOP

BY-PASS POPULATION ZONE IF ZERO

CAL. TONS GENERATED/WEEK

CAL. MINIMUM POP. FOR 1 TON

FLOW DIAGRAM FOR TRIPUT PROGRAM
IN FORTRAN IV



```
155 TONS=TONS(K)
    TRIPS=2.*TONS/IKCAP
    HOURS=(TRIPS*TTIME(I+32)/6000.)+ (U
    COST3=TRCST*HOURS/TONS
    CIJ=(COST3+COST4(J))*100.
    NCIJ(K)=CIJ
    K=K+1
170 CONTINUE
    WRITE(LTW,175)(I,J,NCIJ(I),I=1,M)
175 FORMAT(3I7,59X)
    PRINTING OCCURS EACH TIME THAT COSTS ARE CALCULATED AND STORED
    FROM ALL ZONES TO A DISPOSAL SITE
    WRITE(NPR,178)NCOS(J)
178 FORMAT(39HCCENTROID NUMBER OF DISPOSAL SITE ZONE ,I3)
    WRITE(NPR,180)J
180 FORMAT(50H TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE,I5)
190 CONTINUE
    WRITE(LTW,195)(NZOPOS(I),I=1,M)
195 FORMAT(26I3,2X)
    END FILE LTW
    END FILE LTW
200 WRITE(NPR,210)
210 FORMAT('0','                          REFUSE DISPOSAL SITE SYSTEM DATA')
    WRITE(NPR,220)
220 FORMAT('0','MATRIX  TRANS AVG.WEEKLY  REGIONAL LANDFILL  LAND +SIT
   1E  TOTAL     SITE LAND VAL REMAINING')
    WRITE(NPR,230)
230 FORMAT(' COL NO.  ZONE  DISPOSAL     TOTAL    OPERATION    COST    D
   1ISPOSAL   LIFE   $ PER  CAPACITY')
    WRITE(NPR,240)
240 FORMAT(17X,'(TONS)     PERCENT  $ PER TON  $ PER TON $ PER TON YEAR
   1S   ACRE    (TONS)')
    WRITE(NPR,250)
250 FORMAT('0')
    DO 270 I=1,N
    REGT=PERCNT(I)*100.
    WRITE(NPR,260)I,NZONE(I),NVALS(I),REGT,COST2(I),COST1(I),COST4(I),
   1DSLIFE(I),VLAND(I),CAPLF(I)
260 FORMAT(I5,I9,I9,F11.2,F10.2,F11.2,F10.2,F8.1,F9.0,F10.0)
270 CONTINUE
```

CAL. TRIPS/WEEK

ZONAL TRUCK HOURS

TRUCK COST PER ZONE

TOTAL TRANS. COST

STORE COST IN ARRAY

MATRIX ZONE COUNT

STORE COSTS IN FILE IN CARD FORMAT FOR TRANUV PROGRAM

PRINT CENTROID DISPOSAL NUMBER AND SITE MATRIX POSITION. OR COL. NO.

PRINT DISPOSAL SITE TABLE HEADINGS

PRINT INPUT DATA FOR EACH DISPOSAL SITE

FLOW DIAGRAM FOR TRIPUT PROGRAM
IN FORTRAN IV

```
      WRITE(NPR,275)MNTONS
  275 FORMAT('0','TOTALS',I15)
      WRITE(NPR,280)
  280 FORMAT('1','                    MATRIX POSITION OF TRANSPORTATION ZONES')
      WRITE(NPR,290)
  290 FORMAT('0',10X,'0     1     2     3     4     5     6     7     8
     1     9')
      WRITE(NPR,300)
  300 FORMAT(' ')
      ITEN=0
      LL=M/10
      WRITE(NPR,310) ITEN,(NZOPOS(I),I=1,9)
  310 FORMAT(I6,I12,8I6)
```

PRINT TABLE TO
IDENTIFY EACH
TRANSPORTATION ZONE
NUMBER WITH
ITS CORRESPONDING
MATRIX NUMBER
AS ASSIGNED BY
THE PROGRAM

```
      MM=19
      NN=10
      NSWICH=1
  320 ITEN=ITEN+1
      IF(ITEN-LL)340,330,340
  330 MM=M
      NSWICH=2
  340 WRITE(NPR,350)ITEN,(NZOPOS(I),I=NN,MM)
  350 FORMAT(11I6)
      MM=MM+10
      NN=NN+10
      GO TO (320,365),NSWICH
  365 REWIND LTW
      STOP
      END
```

ALL TRANSPORTATION ZONES
NOT APPEARING IN THIS
TABLE HAVE BEEN DROPPED
BECAUSE OF ZERO POPULA-
TION, OR BECAUSE 1 TON
OF REFUSE PER WEEK HAS
NOT BEEN GENERATED.

IX. THE TRANSPORTATION LINEAR PROGRAM "MODI" SOLUTION METHOD

The original documentation of the transportation program supplied from the IBM 360 library is found in the appendix of this report. A list of background reading material covering the details of the problem solution technique may be found in the bibliography. It is beyond the scope of this report to delve into the mathematical background of proof that justifies the techniques used for the solution of the Transportation Linear Program. Even so, some generalities may be stated in order to prevent misguidance.

The solution of the Transportation Problem has been developed to the point where it may be worked by following a set of rules for the manipulation of numbers without having to know the mathematical proof that justifies the method. The arithmetic of the solution of the problem is done within a framework of squares similar to a checkerboard. The number of blocks in each row is determined by the points of demand which may be warehouses or disposal sites. The number of rows of blocks is determined by the points of supply which may be factories or refuse generation zones. These blocks form the framework of a M x N matrix of numbers, M representing the number of rows and N representing the number of columns.

With the aid of a 4 x 6 matrix illustrated by Figure 3, an attempt will be made to describe in a general way how the TRANUV program moves the tons of supply and demand from block to block, keeps the supply and demand in balance, and assigns the units finally to the combination of blocks that minimizes the the total cost.

The checkerboard format is a symbolic orderly representation of the elements of a system of linear equations. The columns contain the destination elements and the rows the origin elements. The small blocks in each upper left hand corner of the large blocks contain the cost per ton of refuse from origin

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(row) i to destination (col.) j. The values of X_{ij} in circles are the assignments of tons from origins to sites. The b_j values at the botton of each column are the total tons to the site represented by that particular column. The a_i values in the next to last right hand column symbolizes the total tons from each origin. The computer data input is the M x N matrix size, the row totals a_i (zone generated tons), the column totals b_j (disposal site tons acceptance), and costs per ton C_{ij} of refuse from all transportation zones to all sites.

At the start of the solution there are no X_{ij} assignments to the blocks. At this point the computer makes assignments of tons to enough blocks to constitute a basic feasible solution. The number of block assignments that satisfies this condition is M + N - 1. In a 4 x 6 size matrix this would be 4 + 6 - 1 or 9 blocks. The mathematical theory establishes the fact that any fewer initial assignments than this will not permit a problem solution by the transportation linear program algorithm. The initial basic feasible solution is created by the column **minima** method, as is stated in the IBM 360 documentation of the transportation program (See Appendix E). This assignment satisfies the mathematical requirements of a basic feasible solution, but it is only one of many that are not the optimum minimum cost solution. The total transportation cost is calculated by multiplying each assignment of tons by its unit cost and totaling these products. This is the objective function which must ultimately be minimized. It is expressed mathematically as

$$Z = \sum_{ij} Cij\ Xij$$

MATRIX SYMBOLIZATION OF THE TRANSPORTATION LINEAR PROGRAM MODI SOLUTION METHOD

DESTINATIONS

ORIGINS		D_1	D_2	D_3	D_4	D_5	D_6	a_i	u_i
	O_1	C_{11} X_{11}	C_{12} X_{12}	C_{13}	C_{14}	C_{15}	C_{16}	a_1	a_1
	O_2	C_{21}	C_{22} X_{22}	C_{23} X_{23}	C_{24} X_{24}	C_{25}	C_{26}	a_3	u_2
	O_3	C_{31}	C_{32}	C_{33}	C_{34} X_{34}	C_{35} X_{35}	C_{36}	a_3	u_3
	O_4	C_{41}	C_{42}	C_{43}	C_{44}	C_{45} X_{45}	C_{46} X_{46}	a_4	u_4
	b_j	b_1	b_2	b_3	b_4	b_5	b_6		
	v_j	v_1	v_2	v_3	v_4	v_5	v_6		

X_{ij} = The assignment of units (tons) to a origin i and a destination j.

C_{ij} = The cost of shipment and disposal from origin i to destination j.

b_j = The sum of all tons shipped to destination j.

a_i = The sum of all tons generated by destination i.

u_i & v_j = The row and column values that satisfy the equation. $C_{ij}+u_i+v_j = 0$ for the occupied blocks.

FIGURE 3

The computer achieves the minimum cost objective function in a series of iterations. The solution technique is repeated successively. Each time the objective function is lower in value than the previous calculation. Ultimately no lower valued function can be found. This is the optimum solution. The computer then prints all values derived from the last iteration.

The method used by the TRANUV program to solve the Transportation Linear Program, after a basic feasible solution has been found, is the MODI method. This is a modified version of an earlier technique called the Stepping Stone Method. The MODI solution is better adapted for use with digital computers.

The MODI method creates initial assignments of row and column numbers symbolized as u_i and v_j respectively. Some authors call it the uv method, and the numbers may be called simplex multipliers, shadow prices, implicit prices, or the primal dual variables. Each writer seems to love to invent his own jargon. The u_i's and v_j's for the occupied cells are related to each other and the (C_{ij}) cost by the equation. $C_{ij} + u_i + v_j = 0$

An initial assignment of u_i and v_j numbers for the first iteration is done by arbitrarily assuming that the u_i value for the first row is zero. Then from the above equation, C_{11} and u_1 being known, v_1 can be determined (see Fig 3). After having determined the u_i and the v_j for column 1 and row 1, the other values u_2 to u_4 and v_2 to v_6 are calculated by substitution in the same equation.

Knowing all the values of C_{ij}, u_i and v_j and by use of the equation $C'_{ij} = C_{ij} + u_i + v_j$, C_{ij} values can be assigned to each block that does not contain an initial X_{ij} ton assignment[7]. The C'_{ij} values are known as the opportunity costs. Wherever the values of C'_{ij} in a block is less than zero the value of the objective function may be improved by moving tons from another block having a lower cost opportunity. If all the values of C'_{ij} in all the blocks not containing assigned tons are zero or positive then an optimal solution has been achieved. A number of iterations involving the same arithmetical routine may be necessary before this happens.

In each iteration before optimal solution is attained there exists one block that has the most negative value of C'_{ij}. This is the block with the highest cost reduction opportunity. Assigning the maximum allowable tons to this block provides the best opportunity to improve the value of the objective function. Accordingly X_{ij} values (tons) are moved from another column already having tons assigned to it which has the most negative value of C'_{ij}. The amount of tons moved must not cause the tons assignment to go negative in the block from which they were moved. The rules of the game state that the sums of the X_{ij} values in both columns and rows must not change, that is, the a_i and b_j values. In our problem this would mean that the amounts shipped from population zones and the amounts received by the disposal sites must not change. In order to balance the increment of tons added to the block in the column with the most favorable cost opportunity, there must be subtracted the same number of tons from another block in the same column. This block must already contain a tons assignment. Then to balance the increment of tons taken from the original column, tons must be added to another block in the same row, but in another column. To put it another way the tons adjustment is added and subtracted from different blocks in the same row, in order to maintain the same value of a_i for the row and the same value of b_j for the column. All other assignments remain unchanged during the same iteration.

When the above adjustments are made, that iteration is ended, and a new one is initiated. The next iteration is begun by assigning a zero value of u_i arbitrarily to some row, after which all of the u_i and v_j values are recalculated. A new block is again found with the highest cost reduction opportunity. This determines the location again of the next tons reassignment. The computer proceeds from iteration to iteration until all cost opportunities vanish. The assignment of tons from the zones to a disposal site determines the disposal site service area. The minimum value of the objective function (the total cost of transportation and disposal) is calculated by multiplying the unit cost in the blocks with its tons assignment and totalizing the products. A more detailed and theoretical explanation may be obtained from the references at the end of this report.

X. USING THE MODEL*

At the initiation of a problem solution a transportation zone map in required. The Baltimore Regional Transportation Zone Map shows the boundaries of the zones with the zone numbers therein. On this map the refuse disposal sites that will be tested in the problem run are plotted within their respective transportation zones. Each disposal site is numbered continuously beginning with number 1 and continues until all are numbered. The numbering of the sites is done in the order of their transportation zone numbers. Thus, the transportation zones containing disposal sites will be assigned two sets of numbers. The continuous number set will be the column matrix numbers in the TRANUV program problem solution. The disposal site transportation zone numbers are punched in card G (see Fig. 5) in numerical order. All site data punched into cards B, C, D, E, and F are in the numerical order established for card G.

The initial card A of the data deck contains the following constant values determined by the problem:

	Col. Nos.	Constant	Description
1	1 - 2	N	Number of disposal sites
2	3 - 4	LABORS	Number of laborers per truck exclusive of driver
3	5 - 10	PAYLBR	Laborers pay per hour
4	11 - 16	DRDPAY	Drivers pay per hour
5	17 - 22	CSTHR	Truck cost per hour
6	23 - 28	CAPLBS	Refuse generation in lbs per capita per day
7	29 - 32	TKCAP	Tons truck capacity
8	33 - 36	UNLOAD	Time to unload truck
9	37 - 41	WTMIN	Minimum lbs. from each zone per week

---

*Many of the operational problems discussed in this section are related to the operating procedures of the University of Maryland Health Sciences Center. Each agency using this model will no doubt discover their own particular problems.

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Card B contains the fixed refuse disposal costs of incinerators, transfer stations or landfill costs where this is the only available information. The values are arranged in disposal site order. In positions where operation costs of the landfills are calculated by the equation (Figure 9) the field corresponding to that site is left blank.

Into the C cards are punched the decimal percentages of the total refuse to be sent to the disposal sites. The capacity of one card is 12 sites. If more than one card is needed percentage values are assigned from the left on the additional cards. Location of the decimal point is as shown in Figure 4, Card C. All decimal percentages should sum to 100%.

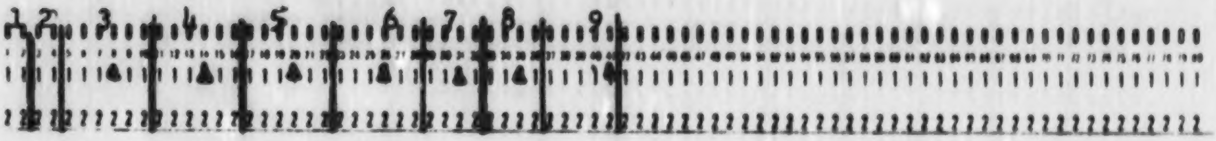
Into D cards are entered the values of the unused disposal site land in dollars per acre. The decimal point is right adjusted and the computer reads the values as real numbers into the VLAND array. Six sites are entered in each D card, and as many cards are used as is necessary. Subsequent site values are put into succeeding cards from left to right. Non-landfill disposal sites are indicated by the entry 99. The format of the card read statement causes columns 73-80 to be unread.

E cards contain the capacity in tons remaining in each of the landfills. The decimal point is right adjusted and values are read as real numbers into the CAPLF array, nine values to a card. Additional site values are punched into succeeding cards from left to right until all site values are entered.

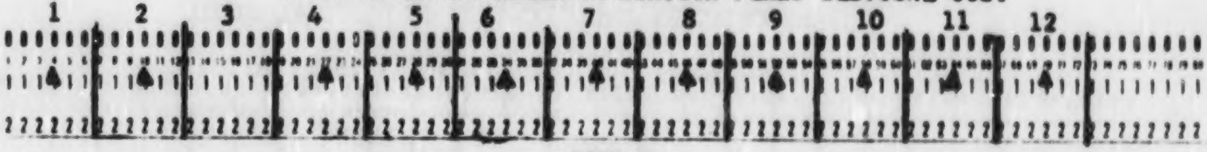
F cards contain integered values of the unused land area at the disposal site, fourteen fields to a card, and all values are in site number order.

FORMAT OF CARD INPUT TO "TRIPUT" PROGRAM

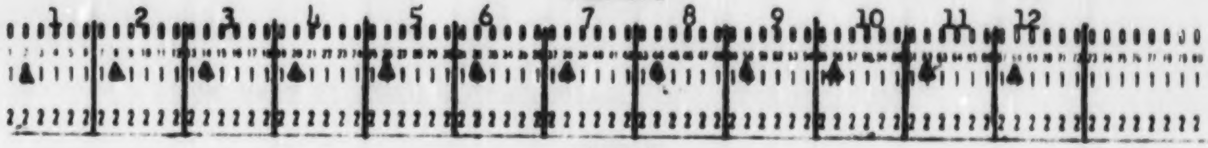
CARD A
REFUSE DISPOSAL CONSTANTS



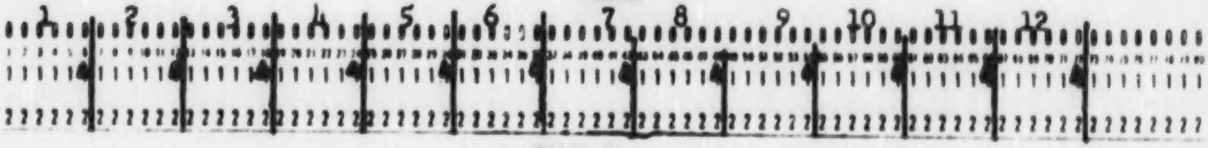
CARD B
INCINERATOR OR TRANSFER STATION FIXED DISPOSAL COST


1
2
3
4
5
6
7
8
9
10
11
12

CARD C
DECIMAL OF TOTAL REGIONAL REFUSE TO DISPOSAL SITES
PERCENT


1
2
3
4
5
6
7
8
9
10
11
12

CARD D
VALUE OF DISPOSAL LAND AT SITES IN $ PER ACRE
VLAND


1
2
3
4
5
6
7
8
9
10
11
12

CARD E
REMAINING CAPACITY OF LANDFILL IN TONS
CAPLF

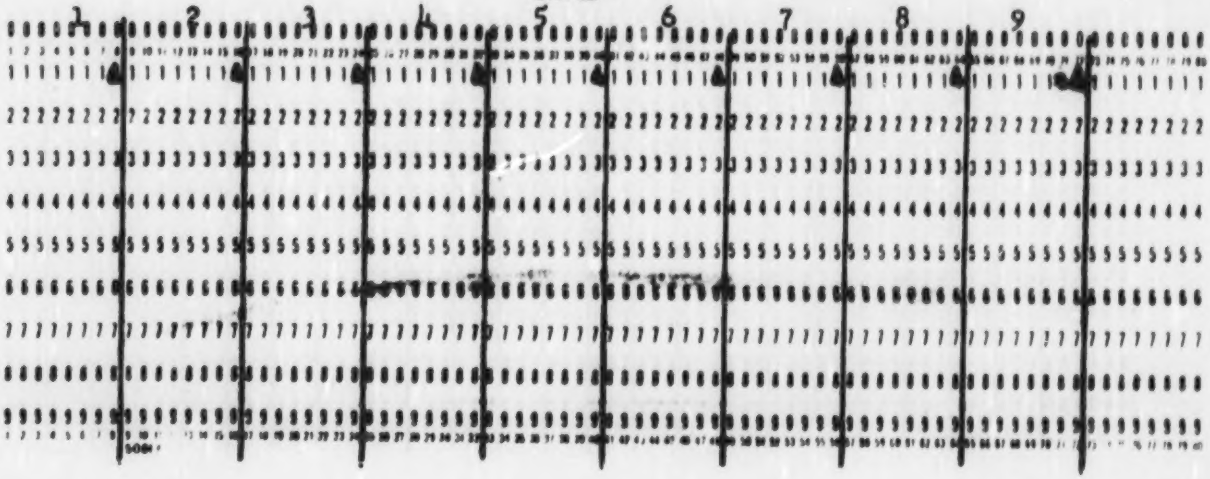
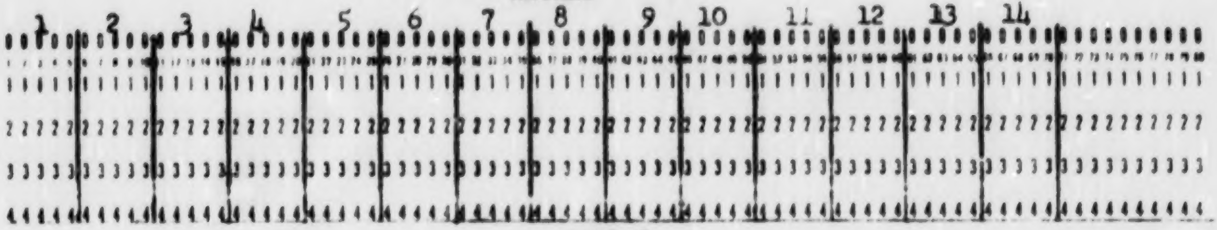


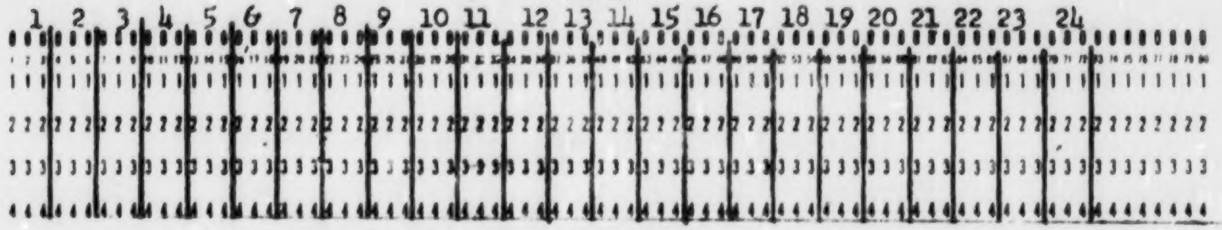
FIGURE 4

FORMAT OF CARD INPUT TO "TRIPUT PROGRAM

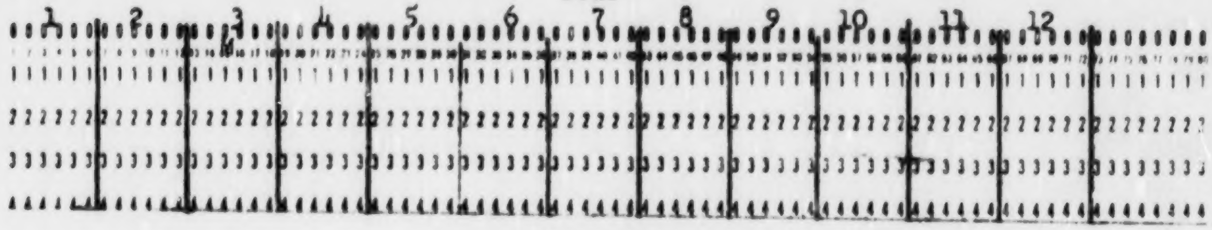
CARD F
REMAINING AREA OF LAND AT DISPOSAL SITE IN ACRES
NACRES


1 2 3 4 5 6 7 8 9 10 11 12 13 14

CARD G
TRANSPORTATION ZONE LOCATION OF DISPOSAL SITES
NZONE


1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

CARD H
POPULATION OF THE TRANSPORTATION ZONES IN ZONE ORDER
NPOP


1 2 3 4 5 6 7 8 9 10 11 12

CARD I
ORDERED LIST OF POPULATION ZONE NUMBERS

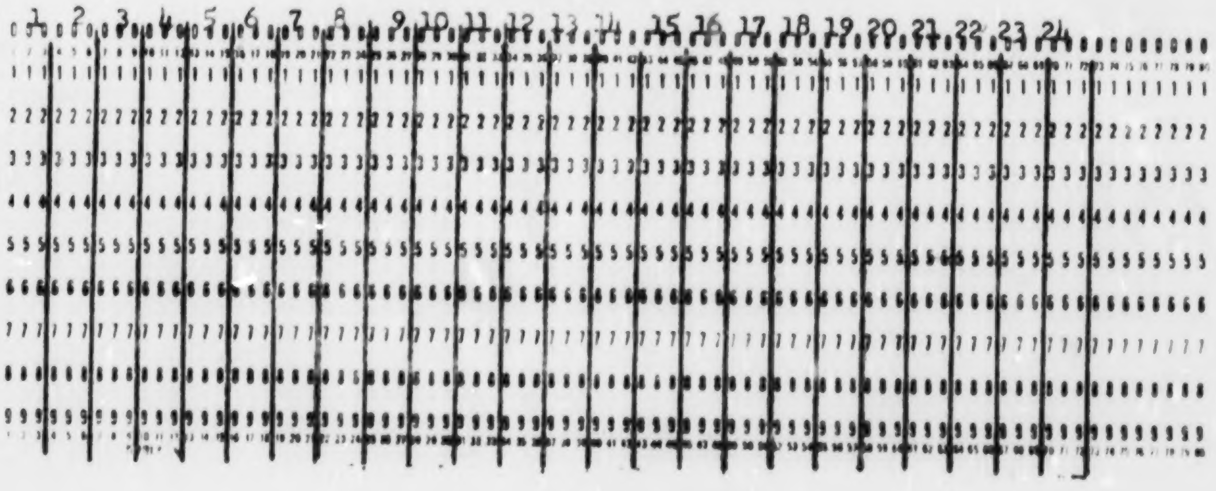

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24

FIGURE 5

Cards H and I contain population and numbers of the transportation zones and will remain unchanged for a particular study. The H cards contain design year populations of the transportation zones, and the I cards contain an ordered list of the transportation zone numbers. The values punched in cards H and I are in the same order as the transportation zone numbers in the G cards. The format for H cards contains twelve fields per card, with six integers allowed for each field. Columns 73 to 80 in all data cards are either blank or are used for identification. The card read format is programmed to bypass these columns.

The only other input data to the model is the Skim Tree tape. Once properly assigned the UNIVAC 1108 machine operators at the computer center location will mount the tape on the tape drives as directed by the UNIVAC Exec 8 system. The only thing of concern to the model user is whether the Skim Tree tape is in the library and ready for use. If the reserve on the tape is allowed to lapse, the tape may be erased or assigned to some other user. The Skim Tree tape is formated in blocks of 679 values. The first value of each block is the block identity number. It is read into a dummy variable location and is not needed for calculations. The blocks of travel times are arranged on the tape in centroid number order. The computer is programmed to read one block at each read command. There is a block of times for each transportation zone, but only blocks representing zones where there exists a disposal site, are read. In FORTRAN terminology the command is an unformated read. (See line 95 in Section VIII).

The TRIPUT program output is put into the FASTRAND file TDUMP for use as input to the TRANUV program. The data format is in card image form as shown in Figure 6. This is the same card input format as the original TRANSPORTATION program for the IBM 360. The TRANUV program is run after the TRIPUT program, and reads its input from the FASTRAND file TDUMP. The TRANUV program may be run as a batch run throught the UNIVAC 9300, or it may be called from the teletype. Since sample problem takes 6.6 minutes of CP (central processing) time to run, running it as a batch job may be more desirable. Otherwise the teletype output might be sporadic or delayed an inordinate amount of time before the final output is delivered.

FORMAT OF CARD IMAGE OUTPUT FROM "TRIPUT" AND INPUT TO "TRANUV" PROGRAM
(ALL VALUES INTERGERED)

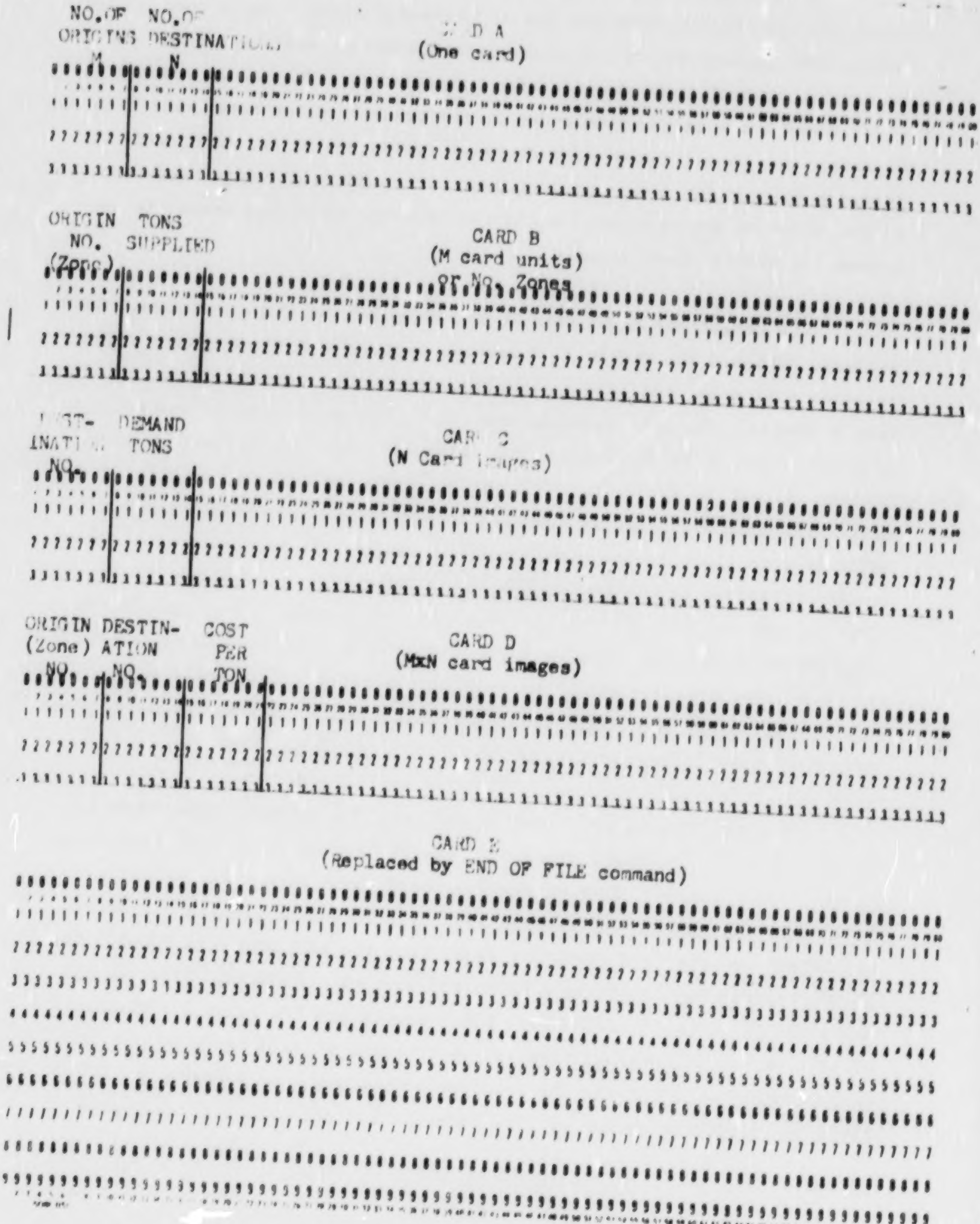

NO. OF ORIGINS M
NO. OF DESTINATIONS N
CARD A
(One card)
ORIGIN NO. (Zone)
TONS SUPPLIED
CARD B
(M card units)
or No. Zones
DEST- INATION NO.
DEMAND TONS
CARD C
(N Card images)
ORIGIN (Zone) NO.
DESTIN- ATION NO.
COST PER TON
CARD D
(MxN card images)
CARD E
(Replaced by END OF FILE command)

FIGURE 6

The TRIPUT program is written to furnish a balanced supply and demand input to the TRANUV program. But, after the data has been put into the TDUMP file by TRIPUT, the demand of the refuse disposal sites may be unbalanced by assigning a surplus of tons to any disposal site. When this is done the sum total of the demand of all the disposal sites is greater than the calculated tons of refuse generated in the transportation zones. When the TRANUV program is operated in this mode, the excess of demand over supply that has the highest cost of transportation and disposal is assigned to a dummy row in the transportation matrix within the computer program. When an optimum solution has been obtained the lower cost assignments are printed as the final answers and the high cost surplus dummy assignments are lost in core. The result is a rebalancing of supply and demand, and a redistribution of refuse into the disposal sites. This redistribution will not agree with the percentages of total refuse which was assigned initially for the input to TRIPUT. In order to have the tables generated by the TRIPUT program compatible with the new TRANUV demand assignments, the TRIPUT program should be rerun with the percentage of assignments in the A cards compatible with the newly generated demands.

Changing a record in a FASTRAND file is accomplished on the UNIVAC 1108 EXEC 8 system by using the @ED statement. This statement may be used to insert images into a program file element or data file. If may also be used to change the image or a portion of the image, or it may be used to delete the entire image. To make a card image change in the TDUMP file from the teletype, first the @RUN statement should be typed, followed by the @ED statement, thus:

```
@RUN¢TDUMP,900-72-127,TRASH,10,100
@ED,U¢TDUMP,ONE
```

The U in the @ED statement is the option character, meaning to create a new cycle of the data file. TDUMP is the file name and ONE is the assigned element name of the file.

After the @RUN and @ED commands are typed the EXEC 8 system goes into the EDIT MODE. At this point the teletype operator has a number of options. As many card images (lines) may be printed as desired by using the command PȼN. The letter P is typed into the first left hand carriage position on the teletype corresponding to column 1 of a card image. Following the P is a blank (ȼ = blank), then is typed (N) the number of lines that are desired to be printed.

To move from the beginning of the file down to a location in the file, in order to make a line or image change, the NȼM command is used. For M is substituted the number of lines from the beginning of the file to the point of stop in the file. When this command is used the M^{th} line is printed (the M of course stands for the line number, or card image in the FASTRAND file).

The M^{th} line may be deleted by typing D. A line may be inserted in this same location by typing I followed by a space. The card image column count starts after the Iȼ. If the data starts in column 7 then 7 plus 2 spaces are counted from the left hand carriage stop, and then the characters are typed. Verification of this line position may be obtained by using a Pȼ1 command. The line just typed will then be automatically retyped, and its column position can be checked. If it is desired to change the supply value of the first site location in the sample problem it would be handled thus:

```
Nç566                         (teletype operator types command)
ççççççlççç2944                (computer automatically types line 566)
Dç                            (this teletype command causes deletion
                               of line 566)
Iççççççççlççç3010             (new demand value of 3010 is typed into
                               site 1)
Pç                            (typing this command causes corrected
                               line 566 to be typed)
ççççççlççç3010                (teletype retypes line just inserted)
```

A move to the next line of the file and any subsequent lines may be accomplished by the N command followed by a blank and the number of lines down through file, the count being made from the last N command. After the teletype carriage return the edit program will print the line moved to in the file. Then, any deletions or insertions may be handled in a similar manner.

After all deletions and insertions are made an @END command terminates the edit mode, and saves the changes in the file. A complete listing of all of the Edit options may be obtained by referring to the UNIVAC 1108 EXEC 8 Operating System Programmers Reference, Section 15, page 19.

When the TRANUV program finds an optimum solution to the transportation problem, four tables are printed. The first table contains the shadow prices for the rows. These are the values u_i as discussed in the section on the TRANSPORTATION LINEAR PROGRAM MODI SOLUTION METHOD. The second table contains the v_j values, that is, the shadow prices for the columns. For an optimum solution the values must satisfy the equation $u_i + v_j \leq C_{ij}$, or the sum of the column and row shadow prices should be equal to or less than the cost value for that row, and column.* The computer program does this job of balancing automatically.

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* Reference 5, page 117

The third table lists the tons assigned from each transportation zone to each site in transportation zone or matrix row number order. The fourth table is the same as the third table except that the tonnages from the transportation zones are grouped for each site. This table in addition sums the total demands, tonnages and costs for each site separately.

After all tables are printed a summation of costs is made for all sites. All values in the tables are in integered form. Costs are all in cents, so that to convert to dollars, the decimal must be placed to the left two positions.

The site capacity of incinerators and transfer stations have a maximum refuse acceptance rate fixed by their design and construction. The acceptance rate of landfills may be varied, but it is inversely proportional to site life. As a result when the acceptance rate of a landfill is being set, the desirable life must be born in mind. By putting refuse into a landfill at a higher rate, the operation cost may be lowered, however, a point may be reached where the shortened life is unacceptable.

After the output is obtained from the TRANUV program the areas of service of each disposal site may be plotted on the transportation zone map. The service area of each site may be established by consulting the last table of the TRANUV program output, and plotting each zone assigned to that site. The completed map will delineate the cost optimized service area for each disposal site in the region.

When the final service areas are drawn, it may be found that some of the transportation zones are separated from the larger mass of the service area. This does not mean that the mathematical solution is incorrect. It may be caused by a situation where two zones are further in map distance than they are in travel times and the model uses travel time, not distance. It may be caused by intervening rivers, airports, reservoirs or other obstacles that require circumventing. Sometimes a transportation zone may have an advantage over another zone by virtue of being near to the entrance of limited access highway, whereas, a closer zone is not. The Solid Waste Transportation Model finds the optimum mathematical cost solution, but practical considerations can be easily imagined that would cause actual route formation to deviate from the optimum solution.

XI. REFUSE GENERATION RATES ON TRUCK ROUTES IN THE BALTIMORE REGION

The Baltimore Region consists of Baltimore City and Anne Arundel, Baltimore, Carroll, Harford and Howard Counties. Of these, only Baltimore County keeps accurate weight records on individual household refuse collection routes. Refuse dispsal collection trucks are weighed at all three of their landfill locations. Truck weights, truck numbers, route numbers, dates and days are recorded on IBM cards at the sites. The cards are accumulated and run through a computer program that generates periodic collection reports. In addition, accurate residential unit counts by streets are maintained defining each collection route. When this information is used in conjunction with a Bureau of Census person per household estimate, a generation rate per capita per day can be calculated.

A study was made of refuse collected over a period of one year involving 49 routes in Baltimore County. The average amount of refuse collected from residences exclusive of commercial pick-ups was 2.23 lbs. per capita per day. The minimum amount collected on any route was 1.33 lbs. per capita per day and maximum was 3.13 lbs. per capita per day.

A study of Baltimore City collection routes was also made. Baltimore City does not keep records of tonnage of refuse picked up from the various collection routes. They do have a record of the number of truck loads of refuse collected from groups of truck routes they call boroughs. Nor were residential unit counts available from these boroughs. The population served had to be estimated from census tracts. The amount of tonnage generated by each borough had to be obtained by multiplying an estimate of the average weight carried by each collection truck by the number of trucks from that borough during the year. A map was available showing the collection areas of the truck routes constituting each borough. From the above data estimates of the generation rates for each borough in lbs. per capita per day were calculated. From planimetered map areas of the boroughs and the apportioned census population the residential gross density was calculated.

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The minimum borough generation rate was 1.61 lbs. per capita per day and the maximum was 2.70 lbs. per capita per day. The average was 2.18 lbs. per capita per day.

Before this study was done it was hoped that some available statistical function could be found that would correlate with refuse generation rate and allow a better estimate than a weighted average. In fact an article published in the Public Works Magazine of February 1970 purported to have determined a correlation between generation rate per capita and population density. Points plotted from their data on semi-logarithmetic graph paper seemed to verify a straight line correlation with data collected from various towns within their study area. Therefore, it seemed reasonable that this correlation could be duplicated from data collected in the Baltimore Region.

The streets serviced by the Baltimore County routes were plotted on regional maps from the residential house count route files, and their areas planimetered. From these areas and populations calculated from residential unit counts, gross densities were calculated. Then points were plotted representing pounds per capita per day versus residential gross route density on both linear and semi-logarithmic graph paper. The result was much like a "shotgun" pattern.

The routes studied were of random shapes and sizes. These shapes result from negotiations between the individual route contractors and the county. In assigning streets to each route, no attempt was made to segregate one type of neighborhood from another. Therefore, collection routes contained various housing densities and income groups. Some routes encompassed parks, institutions, interchanges and other routes encompassed none of these. This condition creates a wide variation of population densities for individual routes.

Numerous conditions could cause a variation in generation rate for which no known statistical parameter can account. There is a prevailing notion that family income is an index of refuse generation. This is difficult to verify in the Baltimore Region because there exists no income data that can be identified with the collection routes. Population density is thought to be related to refuse generation rate, but in Baltimore City and Baltimore County low and high refuse generation rates occur in both high and low density areas.

As the situation exists now there is no known way to anticipate, within the limits of maximum and minimum generation rates, the actual refuse that will be produced on a collection route. Also, it is not known how the generation rate on the routes varies from year to year. The weather is a contributing factor. On routes where houses are surrounded by lawns or unpaved areas, grass clippings, leaves and vegetation make a greater contribution to refuse in wet seasons than during dry ones. This occurs in suburban housing but as the suburbs blend into the rural areas, this tendency diminishes. The low generation rates tend to exist in the high density areas of Baltimore City and the rural low density areas of Baltimore County. Between these areas are the suburban dwellers many of whom maintain a hobby of lawn manicuring.

On some collection routes that serve the shore line areas of rivers tributary to the Chesapeake Bay, there are numerous summer residences that are occupied only four months of the year. This situation causes the generation rate to be less than it otherwise would be. The collection contractors are paid for each residential unit on their route regardless of the occupancy of the housing units.

The problem of estimating the amount of refuse in an arbitrary area, call it a collection route area, population zone or what you will, cannot be solved with the current data that is compiled. A weighted average of all the refuse collected per capita per day is correct only within plus or minus 40%, and it seems that this error within a particular route will have to be accepted as the best that can be obtained for data input to the computer model.

BALTIMORE CITY AND BALTIMORE COUNTY DOMESTIC REFUSE GENERATION FROM COLLECTION ROUTES

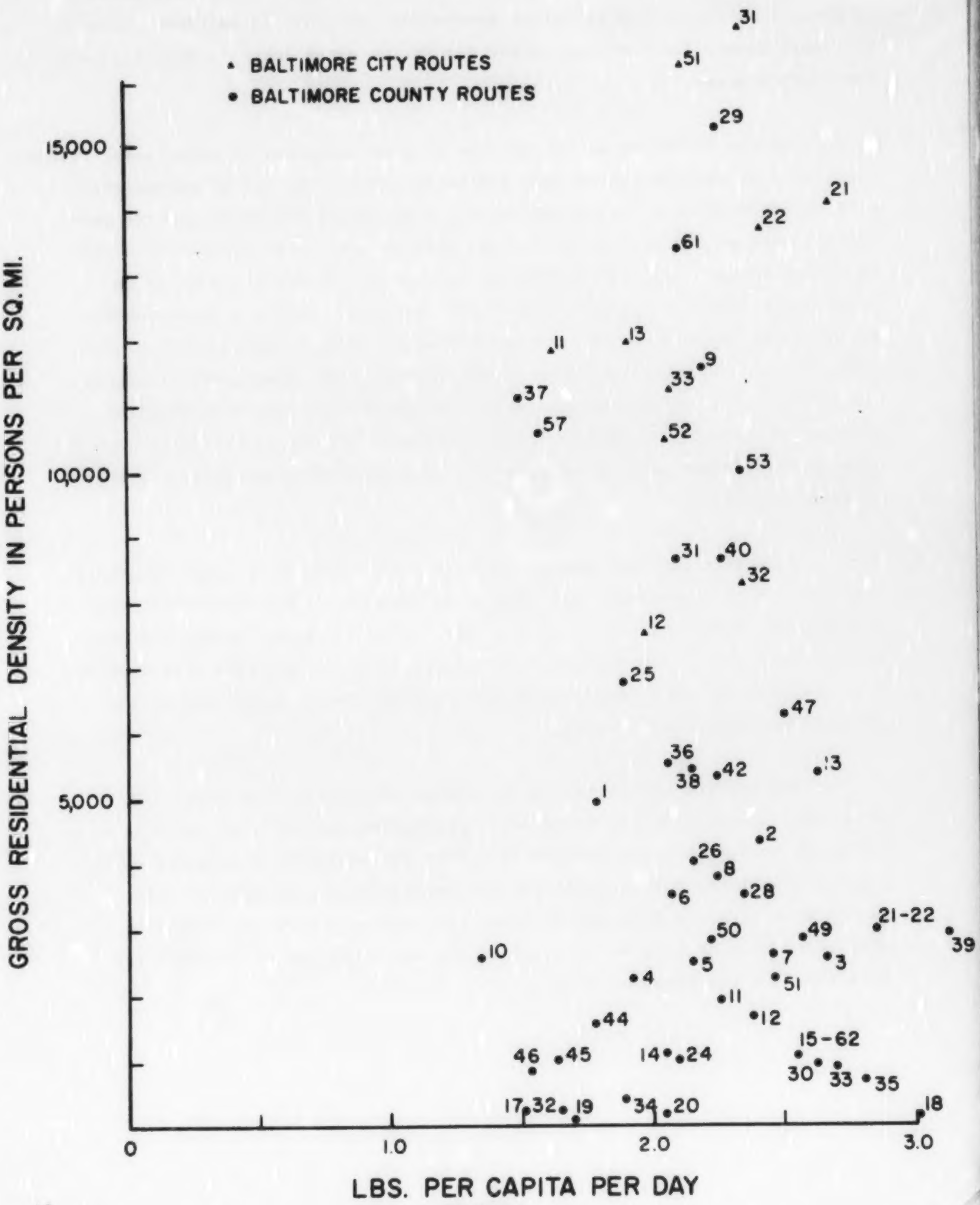

FIGURE 7

BALTIMORE CITY AND BALTIMORE COUNTY DOMESTIC REFUSE GENERATION FROM ROUTES

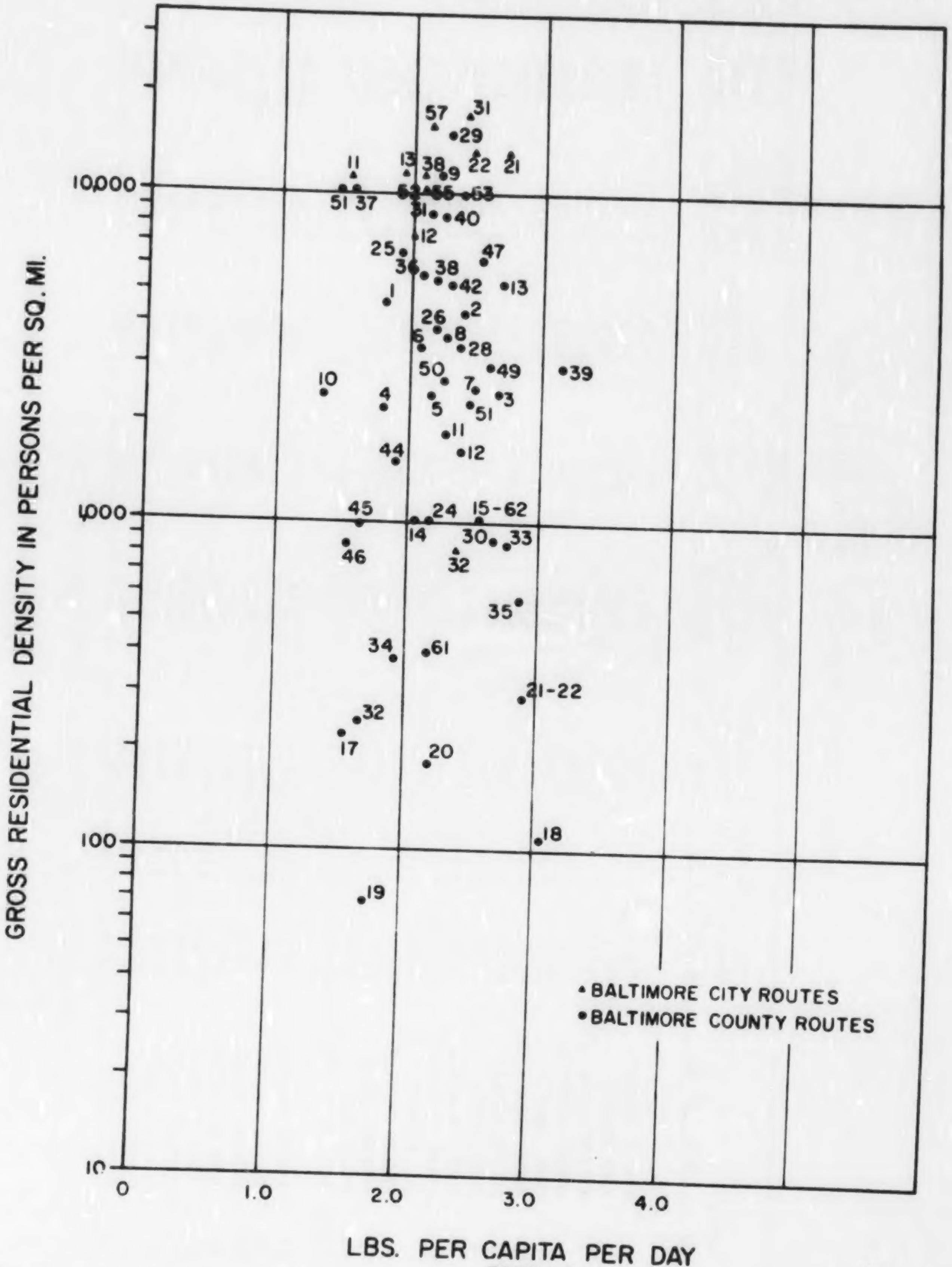

FIGURE 8

TABLE 1

DOMESTIC REFUSE COLLECTION IN BALTIMORE COUNTY

ROUTE NO.	CONTRACTOR	RES. HOUSE UNITS	PERSONS PER H.U.	CALCULATED POPULATION H.U.X.PERSONS	TOTAL TONS REFUSE COLLECTED PER YEAR	COMMERCIAL REFUSE TO DEDUCT (TONS)	NET RESIDENTIAL REFUSE	RES REFUSE COLLECTED PER CAPTIA PER DAY	GROSS ROUTE AREA (ACRES)	GROSS RESIDENTIA DENSITY PERSONS/SQ
1	GEORGE HOFFMAN	2723	3.5	9530	3084	50	3034	1.77	1230	4963
2	JOHN MERSON	2945	3.0	8835	4025	136	3889	2.41	1306	4331
3	NORBERT SPINDLER	7451	3.0	22353	14427	3550	10877	2.67	5712	2503
4	DONALD WARRENER	2788	3.2	8922	3006	-	3006	1.85	4192	2247
5	CHAS. HARVEY	2311	3.2	7395	2980	71	2909	2.16	1920	2465
6	HENRY HORAK	2570	3.2	8224	3120	-	3120	2.08	1540	3500
7	ROBERT HEALEY	2951	3.2	9443	4614	381	4233	2.46	2288	2638
8	FRED. REITZ	2596	3.2	8307	3455	75	3380	2.23	1408	3776
9	ROBT. SPINDLER	3452	3.2	11046	4782	338	4444	2.20	612	11506
10	GERRY GOBRECHT	4389	3.5	15361	3805	78	3727	1.33	3994	2539
11	ED. RUPPERT	3634	3.1	11265	5420	780	4640	2.26	3781	1906
12	NAYLOR RUPPERT	8393	3.1	26018	12373	1015	11358	2.39	9935	1676
13	BERNARD UHLER	6206	3.1	19239	10630	1407	9223	2.63	2323	5300
14	FRED. PAHL	3228	3.5	11298	4281	55	4226	2.05	6644	1088
15-62	MRS. ELLEN COCKY	8891	3.1	27562	13258	422	12836	2.56	3056	1055
17	JOSEPH MICHAEL	2515	3.6	9054	2718	231	2487	1.51	25898	223
18	WILLIAM GERBER	3008	3.5	10528	5908		5908	3.07	59394	114
19	RICHARD PROBST	3643	3.0	10929	3605	104	3501	1.71	101832	69
20	JOHN ALEXANDER	2963	3.0	8889	3693	135	3558	2.19	30405	187
21-22	CLAY STAMBAUGH	11866	3.2	37971	20542	728	19814	2.86	8133	2975
24	LEONARD IMHOFF	2871	3.0	8613	3510	208	3302	2.10	5319	1034
25	ASA N. GERBER	2796	3.0	8388	2913		2913	1.90	794	6760
26	SANDERS BRYAN	2790	3.0	8370	3404	78	3326	2.18	1346	3990
28	HELEN GIBSON	3286	3.0	9858	4468	260	4208	2.34	825	3470

Note: Tons of refuse from routes recorded between 3/29/70 and 3/29/71

TABLE 1
(con't)

DOMESTIC REFUSE COLLECTION IN BALTIMORE COUNTY

ROUTE NO.	CONTRACTOR	RES. HOUSE UNITS	PERSONS PER H.U.	CALCULATED POPULATION H.U.X.PERSONS	TOTAL TONS REFUSE COLLECTED PER YEAR	COMMERCIAL REFUSE TO DEDUCT (TONS)	NET RESIDENTIAL REFUSE	RES. REFUSE COLLECTED PER CAPITA PER DAY	AREA (ACRES)	GROSS RESIDENTI DENSITY PERSONS/S
29	JAMES ANDERSON	3450	3.0	10350	4312	39	4273	2.26	437	15200
30	JOHN BROWN	2450	3.0	7350	3526	13	3513	2.62	5256	895
31	ED. STAMBAUGH	3039	3.0	9117	3497	-	3497	2.10	674	8620
32	ANTHONY MELBER	2546	3.3	8402	2549	78	2471	1.66	21142	254
33	ROLAND PARLET	2182	3.3	7201	3646	52	3594	2.70	5331	865
34	PRICE BROS.	2524	3.3	8329	2867	-	2867	1.89	13670	391
35	GORDON MOHR	2637	3.3	8702	4506	-	4506	2.83	9347	598
36	FRANK HOLLAND	2673	3.3	8821	3602	218	3384	2.08	1016	5508
37	JOHN CLARKE	2640	3.3	8712	2399	-	2399	1.51	504	11100
38	ANTHONY MOHR	2500	3.5	8750	3482	13	3469	2.17	1032	5420
39	ANDY HILL	3199	3.5	11196	6480	88	6392	3.13	2414	2960
40	CASIMIR KANIS	2684	3.3	8857	3754	104	3650	2.26	662	8560
42	THOMAS PAGE	3500	3.2	11200	4598	-	4598	2.25	1358	5290
44	M & G ZAHRADKA	2189	3.2	7005	2338	42	2296	1.79	2789	1610
45	A & M PAKASKI	2570	3.2	8224	2464	13	2451	1.64	5280	1000
46	HARRY HOWELL	2688	3.4	9139	2531	-	2531	1.52	6576	890
47	W. J. BUTTON	2419	3.2	7741	3677	149	3528	2.50	808	6140
48	SCHAFER BROS.	2582	3.2	8662	2832	145	2687	1.70	216	25450*
49	F & H SCHIMINSKY	2634	3.2	8429	4203	251	3952	2.57	1875	2880
50	WM. BARCIKOWSKI	2043	3.4	6946	3137	320	2817	2.22	1600	2775
51	MUESEL TRUCKING	2028	3.4	6895	3233	152	3081	2.46	1912	2300
53	MARSHALL TRASH	4331	3.4	14725	6943	624	6319	2.35	939	9950
55	N. L. WINGATE	14154	3.4	48124	18391	426	17965	2.05	2938	10500
57	J. W. SLOBODA	3504	3.4	11914	3185	-	3185	1.47	734	10650
61	RAYMOND WISE	2516	3.5	8806	3482	78	3404	2.12	13418	420

Note: Tons of refuse from routes recorded between 3/29/70 and 3/29/71

TABLE 2

DOMESTIC REFUSE COLLECTION IN BALTIMORE CITY

BOROUGH NO.	POPULATION	ACRES	SQ. MI.	YEARLY REFUSE (LOADS)	LOADS X4.5= TONS	PERSONS PER SQ. MILE	REF. GEN. LBS/CAPITA PER DAY
11	86,507	4701	7.35	5678	25,551	11,770	1.61
12	75,403	6410	10.00	6050	27,225	7,540	1.98
13	77,409	4131	6.46	5998	26,991	11,983	1.91
21	107,251	4925	7.69	11748	52,866	13,946	2.70
22	95,789	4499	7.03	9398	42,291	13,626	2.42
31	87,064	3334	5.21	8412	37,854	16,711	2.38
32	90,088	6978	10.90	8595	38,678	8,265	2.35
33	106,793	6100	9.53	9040	40,680	11,206	2.09
51	92,302	3648	5.70	7978	35,901	16,193	2.13
52	102,937	6301	9.85	8677	39,092	10,450	2.08

Note: Loads of refuse from routes recorded during 1970 and 1971

XII. DETERMINATION OF LANDFILL CAPACITIES

The amount of refuse that can be placed into a landfill is determined by the degree of compaction that can be obtained. In order to determine the life of a landfill its capacity must be calculated. A logical unit of measurement to use for this purpose is tons. Input tons are more convenient to measure than cu.yds. and the measurement of tons is the present trend where more accurate accounting methods are desired. To calculate the tons capacity of a landfill the measurement of cu.yds. must get involved nevertheless. After the space available in the landfill has been determined by the calculation of the cu.yd. capacity, a conversion to tons capacity must be done by multiplying by the lbs. per cu.yd. that each cu.yd. will accept. At the present time this is the area of ignorance that causes the calculation of tons capcity to be so elastic. Estimates of lbs. per cu.yd. density of refuse compacted into the landfill range between 500 and 1250 lbs. per cu.yd.[11,12]. In addition landfill operators do not have a clear idea of how to take advantage of the available space.

An analogy to this situation is the case in which one is in possession of an extra storage room. If the surplus items to be stored are merely taken into the room and dumped without giving it further thought, before long it appears that the storage room has reached its capacity, but if care is taken to place the items into the space in an orderly manner, it is discovered that considerably more space is available. This is the case typifying the operation of most landfills. In order to preserve the limited space available, in the future a greater passion for orderliness must be developed.

The situation that exists when trying to calculate the capacity of a landfill for compacted refuse also exists when attempting to calculate the capacity of the landfill for incinerator residue. In order to establish some system of accounting for the amount of refuse and incinerator residue that a landfill will accept, a figure for lbs. per cu.yd. must be established. A reasonable figure for compacted refuse is 800 lbs. per cu.yd. For incinerator residue a figure of 5.4* tons of refuse per cu.yd. has been mentioned. These figures are not without assumptions. Assume that there is a refuse weight reduction to 20% of the original unburned refuse, then assuming 5.4 tons per cu.yd., the incinerator residue would weigh 2160 lbs. per cu.yd. or 80 lbs. per cu.ft. If only a reduction to 25% in weight were assumed then the incinerator residue would weigh 2700 lbs. per cu.yd. or 100 lbs. per cu.ft. By indulging in a latitude of assumptions various figures for lbs. of refuse per cu.yd. may be seemingly justified.

Considering the state of landfill capcity estimating, it is no surprise that landfills exhibit an uncertain life expectancy. Without a reasonably accurate accounting of the landfill capacities, the solution of the transportation problem can only amount to a rough estimate of disposal costs. Therefore, it is recommended that all landfill management maintain a continuous inventory of the space already filled and the remaining space available to be filled. This accounting should be expressed in tons of compacted refuse in place.

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*Reference 13, page 96

XIII. LANDFILL OPERATION COSTS IN THE BALTIMORE REGION

Of the five counties within the Baltimore Region that operate landfills, none maintain a cost accounting system that reveals an accurate cost of operation on a tonnage basis. An estimate of the cost of operation is obtained by dividing the estimated tonnage input to all landfills into the total money appropriated to operate the bureau. By this method of cost estimation all landfills within any one county are presumed to have the same cost of operation. In all counties except Baltimore County no weighing of refuse trucks is practiced, nor are the number of trucks dumping at the landfills recorded (Baltimore City refuse goes to incinerators).

To get a better landfill costs of operation estimate, a detailed study was made of eleven landfill sites in three counties. The counties investigated were Baltimore, Carroll and Harford. Anne Arundel County was omitted because most of the landfills were operated by private contractors, and the largest landfill operated by the county (Smucks) was just getting started. Weighing is planned there, but has not yet begun, and records have not yet been accumulated. The two landfills in operation in Howard County were not investigated, because of the lack of recorded information.

The study consisted of obtaining the cost of earth moving equipment in use at each landfill, the number of operating personnel, the wage rates, the hours worked, and the amount of money spent on maintenance of equipment. Generally all counties knew the initial cost of the landfill equipment, although some equipment was not owned by the county, but was rented from private contractors. In some cases initial ditching was done by county equipment and in other cases the entire initial excavation was done by private contractors. In some cases records were available for maintenance of each separate piece of equipment. In others the entire maintenance cost of all equipment was lumped together, and the maintenance costs for each piece of equipment had to be allocated to each landfill on a tonnage input basis.

No uniform cost accounting method for determining landfill operation costs is in use that will enable the operation cost of one location to be accurately compared with that of another. In some instances equipment is purchased on borrowed money, and the cost charged off periodically on an amortization basis at the current interest rate. In other cases the equipment is bought for cash and either paid for by direct appropriation or by obtaining the cash from a revolving fund. In some cases equipment is borrowed from the highway maintenance department, and the cost is not allocated to the refuse disposal account. Other disposal services that occur infrequently never get charged to the landfill operation account. An example is the control of accidental fires on the landfill by fire department equipment. Another cost that gets lost is that of storm drain installation which comes as an afterthought, and which should have been anticipated when the landfill was originally planned.

There is almost always a question of how much overhead expense should be charged to the landfill operation. The cost of employee fringe benefits and the county contribution to social security and pension funds, should be added to the cost of landfill operation, but is often forgotten. This amounts to about 10% of an employees gross wages.

The non-uniformity or lack of cost accounting methods that prevail in the Baltimore Region apparently exist throughout the United States. In the Solid Waste Report of June 14, 1971 on page 108, a listing of 32 cities is reported with landfill operation costs. The table is purported to be a reprint of "Trash and Technology--1971" prepared by Walter R. Niessen, of Arthur D. Little, Inc. for the Environmental Quality Conference for Extractive Industries of American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc. held in Washington, D.C., June 7-9, 1971.

ESTIMATES OF SOLID WASTE MANAGEMENT COSTS (In dollars per ton)

	Collection	Incineration	Landfill
Atlanta, Ga.	$12.15	$3.80	$0.80
Baltimore, Md.	10.62	3.40	-
Boston, Mass.	5.72	5.89	2.45
Columbus, O.	4.77	-	1.50
Dallas, Texas	14.75	-	1.17
Detroit, Mich.	13.68	8.87 High	5.55 High
Houston, Texas	17.40	-	-
Indianapolis, Ind.	4.72	4.50	3.00
Los Angeles, Calif.	4.83	-	0.67
Milwaukee, Wis.	10.14	7.83	1.95
New York, N.Y.	16.28	5.53	1.12
Philadelphia, Pa.	6.19	7.19	-
St. Louis, Mo.	11.91	1.98 Low	-
San Antonio, Texas	18.76 High	-	0.50
San Diego, Calif.	5.66	-	1.03
San Francisco	13.09	-	3.50
Seattle, Wash.	8.08	-	4.00
Lodi, Calif.	5.18	-	1.23
Palo Alto, Calif.	9.12	-	1.66
Woodland, Calif.	7.79	-	4.92
Phoenix, Ariz.	6.28	-	1.03
Tucson, Ariz.	5.41	-	0.60
Berkeley, Calif.	4.29	-	0.51
Beverly Hills, Calif.	9.10	-	1.01
Colton, Calif.	4.21	-	0.44
Covina, Calif.	5.84	-	0.40
Hanford, Calif.	7.83	-	0.78
Inglewood, Calif.	2.72 Low	-	0.37
Madera, Calif.	4.77	-	5.46
Oceanside, Calif.	4.94	-	0.35
Oxnard, Calif.	4.70	-	0.68
Pacific Grove, Calif.	5.15	-	0.40

ESTIMATES OF SOLID WASTE MANAGEMENT COST (In dollars per ton) (Cont'd)

	Collection	Incineration	Landfill
Pasadena Calif.	$4.85	$-	$0.29 Low
Pomona, Calif.	4.81	-	0.50
Riverside, Calif.	6.91	-	1.04
San Bernadino, Calif.	5.33	-	0.48
Dekalb Co., Ga.	-	3.46	-
Alexandria, Va.	-	7.26	-
New Orleans, La.	-	4.73	-
Atlanta, Ga.	-	6.69	-
Ogden, Utah	-	3.29	-
Average	$8.00	$5.30	$1.55

The city with the lowest reported landfill operation cost is Pasadena, California with $.29 per ton and the city with the highest cost is Detroit, Michigan with $5.55 per ton. Other cities costs range between these limits. Like so many among the great proliferation of costs appearing in the refuse disposal literature, the components of the quoted costs are not discussed. A quotation of landfill costs such as this is more confusing than elucidating. It causes the reader to doubt the integrity of the accounting systems used in calculating these costs. A perusal of this cost list poses many questions and answers none. Does the landfill cost include land cost and site development? Was there any site development? Was the landfill operation substandard? At a landfill cost of $.29 per ton was prison labor being used? Was any covering equipment being used on the landfill? Or was it just an open dump?

From the eleven landfills investigated in the three counties of the Baltimore Region an attempt was made to use a uniform method of cost calculation with the limited information available. It seems logical that landfill operation costs should be kept separated from land costs and site development costs, because the operating cost per ton changes with the refuse input to the site, whereas the land cost and site development costs per ton remain constant regardless of the input tonnage over a given time period.

On the following pages is a cost analysis of the eleven landfills that were investigated. From the unit costs derived and the estimated tonnage a curve of costs was plotted. A polynomial curve was made to fit this data. All of the landfill costs fall close to this curve except that for Reliable Landfill in Baltimore County. The unit cost per ton at this location is higher than that indicated by the curve, because of the necessity to engage 5 trucks to haul cover material from an off site location. An equation was fitted to the data points by use of a library computer program available on the CAC time sharing system from a teletype in the Regional Planning Council's office in Baltimore. This equation is used in the Solid Waste Transportation and Disposal Cost Computer Model to determine landfill operation costs at various refuse inputs. Figure 9 in this report is a reproduction of this curve. The equation fitted to this curve is limited on the low end by 25 tons per day and on the high end by 500 tons per day. Further extrapolation of the curve beyond 500 tons per day by use of the polynomial equation will cause errors. If data is obtained for landfills of greater capacity a new polynomial curve may be fitted to the new data, and the new equation substituted into the computer program at the same location (See line 85 of TRIPUT flow diagram). All cost curves are perishable and they must be re-created from time to time to bring them up to date.

CALCULATION OF LANDFILL OPERATION COSTS IN THE BALTIMORE REGION

HERNWOOD LANDFILL - BALTIMORE COUNTY

Equipment Cost

1 D8 Caterpillar Tractor Bulldozer	$ 73,000	
1 Caterpillar Tractor pan scraper cable drawn	10,000	
1 International Harvester 250B crawler tractor cost minus trade in at end of 5 years	35,010	118,010
Weighing scales and scale house	5,857	
Total initial cost of equipment	$123,867	

Assume that the county pays cash for the earth moving equipment and that the life of the equipment is 5 yrs for the earth moving equipment and 10 years for the scales

Charge per week for earth moving equipment 118,010/52 x 5	$ 453.88
Charge per week for scales 5857/52 x 10	11.26

Cost of Labor

	Cost per week
2 Equipment operators #3 @$3.96/hr. Assuming 40 hrs/wk plus 5 hrs overtime at 1½ x regular rate 2(3.96 x 47.5)	$ 376.20
1 Foreman @$4.96/hr. Assuming 40 hrs/wk + 5 hrs overtime at 1½ times regular rate 4.96 x 47.5	235.60
1/3 Supt. of Landfill @$17,000/yr. (17,000/3)÷ 52	108.97
1 scale master @$5954/yr $5954/52	114.40
1 Cashier (Paid from Office of Finance pay roll) @$5954/yr.	114.50
Total Labor cost for landfill	$ 949.77
Add 10% for SS, Health Insurance and pension fund	94.97
Total cost of labor used on landfill	$1,044.74

HERNWOOD LANDFILL - BALTIMORE COUNTY (Cont'd)

Equipment Repairs, gasoline, tires, oil and maintenance	Cost per week
International crawler tractor $9,673.92 for fiscal year 1970-71 $9,673.92/52	$ 186.04
D8 Caterpillar Tractor for ½ year $1,534.18	59.01
Caterpillar Tractor pan for ½ year $1,228.80	47.26
Total cost of all landfill equipment maintenance	$ 292.31

Cost of Operation at Hernwood	Cost per week
Labor	$1,044.74
Earth moving equipment	453.88
Scales	11.26
Maintenance, repairs, gas and oil, etc.	292.31
Total	$1,802.19

Refuse tonnage input to landfill = 1500 Tons/wk = 250 Tons/day

Cost of operating Hernwood Landfill per Ton of refuse =

$1,802.19/1500 $ 1.20 /ton
@ 250 tons/day

CALCULATION OF LANDFILL OPERATION COSTS IN THE BALTIMORE REGION

RELIABLE LANDFILL BALTIMORE COUNTY

Equipment Costs	Purchase Cost	Rental
1 Allis Chalmers 8C 21 Bulldozer	$ 50,532	
1 8242 Euclid Bulldozer	61,215	
1 International TD25 Bulldozer (rental fee)		$16,800/
1 977 K Caterpillar Tractor Front-end loader	40,006	
1 Trojan 3000 Front-end loader	31,063	
5 Tandem Dump Trucks	118,066	
Total Cost of Equipment	$300,882	

	Weekly Charge
Cost of Equipment based on 5-year life ($300,882/5)÷52	$1,157.24
Cost of TD25 Bulldozer $16,800/52 (rental)	323.08
Scale cost $5,992 and based on an estimated life of 10 years(5,992/10)÷ 52	11.52
Total Equipment Charge	$1,491.84

Cost of Labor	Cost per week
1 Heavy Duty auto mechanic @$11,000/yr.	$ 211.54
1 Foreman 4.96/hr. @ 40 hrs/wk + 5 hrs overtime 4.96 * 47.5	235.60
5 Equipment operators #3 @$3.96/hr @40 hrs + 5 OT 5(3.96 * 47.5) = 5 x 188.10	940.50
5 Truck drivers Equipment operators #2 @ $7,488/yr. each = 5 (7,488/52)	720.00
1 Scale master @ 5,954/yr.	114.50
1/3 cost of Supt. of Landfills @ $17,000	108.97
	$2,445.61
Add 10% for SS, Health Ins., and Pension fund	244.56
Total Labor Cost	$2,690.17

RELIABLE LANDFILL - BALTIMORE COUNTY (Cont'd)

Equipment Costs and Repairs	Cost per year	Cost per week
1 Allis Chalmers 8C21 Bulldozer	$20,711	$ 398.29
1 8242 Euclid Bulldozer (½ year)	1,249	48.03
1 International Harvester TD25 Bulldozer	6,641	127.71
1 977K Caterpillar Tractor Front end loader	15,893	305.63
1 Trojan 3000 front end loader	10,383	199.67
5 Trucks @ $3,427/yr. (estimated from one)	17,135	229.52
Total equipment repair and maintenance		$1,308.85

Cost of Operation at Reliable	Cost per week
Labor	$2,690.17
Earth moving equipment including scales	1,491.84
Maintenance Repairs, gas and oil	1,308.85
Total cost of operation per week	$5,490.80

Input to landfill ($\overset{2/3}{\text{commercial}}$ + $\overset{1/3}{\text{domestic}}$ 4,000 tons/wk.

= 667 Tons/day

Cost of Operation = $\frac{5490.86}{4000}$ = $1.37/Ton @ 667 tons/day

CALCULATION OF LANDFILL OPERATION COST IN THE BALTIMORE REGION

TEXAS LANDFILL - BALTIMORE COUNTY

Equipment Costs	Initial Cost
2 -8240 Euclid Bulldozers	$ 53,690
Cable controlled and ripper	42,663
1 Caterpiller 980 compactor	53,112
1 Caterpillar Pan cable control	17,200
1 Trojan 3000 front end loader	32,256
1 8C21 Allis Chalmers Bulldozer	64,145
All of the above equipment estimate to last 5 yrs.	
Total initial cost of earth moving equipment	$ 263,066
Charge for earth moving equipment per week $263.066/(5 x 52)	1,011.79/wk.
Charge for scales per week estimated to have a life of 10 years = $6,140/52 x 10	11.81/wk.
Total weekly charge for equipment =	$1,023.60

Cost of Labor	Cost per week
47.5 hours	
1 Foreman @ $4.96 hr * (40 hrs + 5 OT hrs)	$ 235.60
3 Equipment operators @ $3.96/hr * 47.5	564.30
1 Laborer chauffeur @ $3.11/hr * 47.5	147.72
1 RR crossing guard @ $3.11/hr * 47.5	147.72
1 scale master $5,954/yr ÷ 52	114.50
1 cashier $5,954 ÷ 52	114.50
1/3 Cost Supt. of landfill @ 17,000	108.97
	$1,433.31
Add 10% for SS, Health Ins., and Pension fund	143.33
Total labor cost	$1,576.64

Equipment repairs, gasoline, oil, tires and maintenance	Cost per year
1 Trojan 3000 Front end loader	$ 1,344
1 8C21 Allis Chalmers Bulldozer	10,618
1 Euclid 8240 Bulldozer	16,523
1 Euclid 8240 Bulldozer	19,986
1 Caterpillar pan	1,120
1 Caterpillar 980 compactor	10,080
	$59,671
Cost of equipment maintenance/wk $59,671/52	$1,147.52/wk.

TEXAS LANDFILL - BALTIMORE COUNTY (Cont'd)

Cost of Operation at Texas	
Labor	$1,576.64
Earth moving equipment	1,011.79
Scales	11.81
Maintenance repairs, gas, and oil	1,147.52
Total cost of operation per week	$3,747.76

Input to Texas 3500 Tons/wk = 583 Tons/day

Cost of operation/Ton = $\frac{3747.76}{3500}$ = $1.07/Ton @ 583 tons/day

CALCULATION OF LANDFILL OPERATION COSTS IN THE BALTIMORE REGION

Tollgate-Harford County

Equipment Costs

1 966 Caterpillar Tractor rubber tired loader		$ 49,677
Equipment used on all 5 Harford County landfills		
1 Michigan Model 110-14 self-loading scraper	$62,282	
1 D6 Caterpillar Tractor	14,400	
29.1% of Capital Charge on Equipment used to dig trenches on all landfills $76,682 x .291		22,314
Total equipment cost at Tollgate Landfill		71,991
Cost of equipment spread over 5 years = $\frac{71991}{5 \times 52}$ =		$ 276.89/wk.

Cost of Labor

1 Equipment Operator 65 hrs @$3.75/hr. = 40 + 37½* =77½ hrs * $3.75	$ 290.63/wk.
29.1% of Equipment operators wages on ditching equipment used on all landfills $560.70 x .291	163.16/wk.
1/5 of superintendent's salary (estimated)	50.00/wk.
	503.79/wk.
Add 10% for SS, Health benefits, and pension fund	50.38
Total Labor Cost at Tollgate Landfill	$ 554.17/wk.

Cost of Labor to operate ditching equipment used on all landfills

1 Equipment operator 60 hrs @$3.92/hr. 40 + 30 = 70 x $3.92	$ 274.40/wk.
1 Equipment operator 60 hrs @$4.09/hr. 40 + 30 = 70 x 4.09	$ 286.30/wk.
	$ 560.70

* 37½ hours pay for 25 hours at time and one half.

Tollgate-Harford County (con't)

Cost of Equipment repairs on all landfills

Money spent on repairs during one quarter	$ 16,051.64
Overtime pay (13 weeks)	10,662.40
	$ 26,714.04
Road maintenance material cost on all landfills during 1 quarter (13 weeks)	1,741.06
	$ 28,455.10
Equipment repair and maintenance 1 wk. all landfills $28,455.10/13	$ 2,188.85
Charge to landfill on tonnage input basis 29.1 x 2,188.85 =	$ 636.96

Cost of Operation Tollgate Landfill

	Cost per week
Earthmoving equipment capital charge	$ 276.89
Labor	554.17
Equipment repair and maintenance	636.96
Total Cost of operation of landfill	$ 1,468.02

Estimated input tonnage at Tollgate 800^T/wk. or 29.1% of total input to 5 landfills in Harford County = 133 tons/day

Unit cost of operation at Tollgate = $\frac{1468.02}{800}$ = 1.84/ton @ 133 tons/day

CALCULATION OF LANDFILL OPERATION COSTS IN THE BALTIMORE REGION

MADONNA LANDFILL HARFORD COUNTY

Equipment Costs	
1 Caterpillar 977 Crawler Loader	$ 22,705
3.6% of equipment cost used on all 5 landfills for ditching .036 x $76,682	2,861
Total Equipment Cost at Madonna	$ 25,566
Capital charge based on an estimated 5 year life = 25,566/(5 x 52)	$ 98.33/wk.

Cost of Labor	Cost per week
1 equipment operator 17 hours @$3.66/hr. This is a highway dept. employee who spends 1/3 of his time on the landfill and 2/3 on road maintenance	$ 62.22
3.6% of labor cost of operating ditching equipment used on all landfills .036 x 560.70	$ 20.19
1/5 of Superintendent's salary (estimated)	50.00
	$ 132.41
Add 10% for SS, Health Ins., and Pension Fund	$ 13.24
Total labor cost at Madonna Landfill	145.65

Cost of equipment repairs and maintenance	
3.6% of total cost of maintenance and repairs on all 5 landfills .036 x 636.96 =	$ 22.93

Cost of Operation	
Earth moving equipment capital charge	$ 98.33
Labor	145.65
Equipment maintenance and repairs	22.93
Total cost of operation of Madonna landfill	266.91

Estimated input tonnage at Madonna =

100 Tons/wk = 17 Tons/day = 3.6% of total of all county landfills

Unit cost of operation = $\frac{\$266.91}{100^{T}}$ = $2.67/Ton @ 17 tons/day

CALCULATION OF LANDFILL OPERATION COSTS IN THE BALTIMORE REGION

ABINGTON LANDFILL - HARFORD COUNTY

Equipment Costs

1 955 Caterpillar loader crawler	$ 31,539
21.8% Capital charge of equipment used on all landfills for ditch digging .218 x 76,682	16,717
Total equipment cost at Abington Landfill	$ 48,256
Cost of equipment based on 5 yr. life $48,256/(5*52)	$185.60/wk.

Cost of Labor	Cost per week
1 Equipment operator @3.06/hr. *(40 + $\overset{\text{OT}}{37.5}$) = 77.5	$ 237.15
21.8% of Labor cost of ditching equipment operation .218 x $560.76	122.23
1/5 of superintendent's salary (estimated)	50.00
	$ 409.38
Add 10% for SS, Health Ins., and Pension fund	40.94
Total cost of labor at Abington Landfill	$ 450.32

Cost of Equipment Repairs and Maintenance

Total cost of all equipment maintenance in county	$2,188.85/wk.
Cost of maintenance and repairs based on tonnage input to landfill ratio to total input of county = .218 x $2,188.85	$ 477.17/wk.

Cost of Operation	Cost per week
Earth moving equipment capital charge	$ 185.60
Labor	450.32
Equipment maintenance, repairs	477.17
Total cost of operation of landfill	$1,113.09

Input to Abington landfill 600 tons/wk. (estimated) = 100 Tons/day

Cost of operation of Abington Landfill $\frac{\$1,113.09}{600}$ = $1.86/Ton at 100 Tons per day

CALCULATION OF LANDFILL OPERATION COSTS IN THE BALTIMORE REGION

MULLINS LANDFILL, ABERDEEN, HARFORD COUNTY

Equipment Costs

1 966 Caterpillar rubber tired loader	$ 49,677
36.4% of equipment cost used on all landfills for ditch digging .364 x $766.82	27,912
Total equipment cost at Mullins Landfill	$ 77,589
Capital charge for equipment based on 5-year life without interest $77,589/(52 x 5)	$298.42/wk.

Cost of Labor

	Cost per week
1 equipment operator @$3.49/hr. for 60 hr/wk 3.49 x (40 $\underset{70}{+}$ 30)	$ 244.30
36.4% of labor cost of operating ditching equipment used on all landfills .364 x $560.70 =	204.09
1/5 of superintendents salary (estimated)	50.00
	$ 498.39
Add 10% for SS, Health Ins., and Pension fund	49.84
Total labor cost at Mullins Landfill	$ 548.23

Cost of Equipment Maintenance

36.4% of Cost of equipment maintenance for all landfills .364 x $2,188.85	$ 796.74

Cost of Operation

	Cost per week
Earth moving equipment capital charge	$ 298.42
Labor	548.23
Equipment repair and maintenance	796.74
Total cost of operation of landfill	$1,643.39

Estimated input tonnage at Mullins = 36.5% of total of 5 landfills in Harford County = 1000 Tons/wk. = 167 Tons/Day

Unit cost of operation = $\frac{\$1,643.39}{1000}$ = $1.64/Ton @ 167 tons/day

CALCULATION OF LANDFILL OPERATION COSTS IN THE BALTIMORE REGION

SCARBOROUGH LANDFILL - HARFORD COUNTY

1 Allis Chalmers crawler loader 12G	$ 34,430
9.1% equipment cost used on all landfills for ditching (.091 × $76,682)	6,978
Total cost of equipment at Scarborough	$ 41,408
Cost based on 5 yr. life = $41,408/(5 x 52)	$159.26/wk.

Cost of Labor	Cost per week
1 equipment operator 65 hrs @3.49	
40 hrs + 37.5 (OT hrs) = 77.5 × 3.49 =	$ 270.48
9.1% of labor cost of operating ditching equipment used on all landfills .091 × $560.70 =	51.02
1/5 of Superintendent salary for supervision (estimated)	50.00
	$ 371.50
Add 10% for SS, Health Ins. & Pension fund	37.15
Total labor cost at Scarborough landfill	$ 408.65

Cost of Equipment Repairs And Maintenance

9.1% of total cost of all maintenance and repairs on all 5 landfills .091 × 636.96 =	$ 57.96

Cost of Operation	Cost per week
Earth moving equipment capital charge	$ 159.26
Labor	408.65
Equipment repair and maintenance	57.96
Total cost of operation of Scarborough landfill	$ 625.87

Estimated input to landfill = 250 Tons/wk = 42 Tons/Day
= 9.1% of Total of County

Unit Cost of operation = $\frac{625.87}{250}$ = \$2.50/Ton at 42 Tons per day

CALCULATION OF LANDFILL OPERATION COSTS IN THE BALTIMORE REGION

KATE WAGNER LANDFILL - CARROLL COUNTY

Equipment Costs

1 Front end loader caterpillar 951B	$ 25,000
Cost of loader based on 5 yr life $25,000/(5 x 52)	$ 96.15/wk.

Cost of Labor

	Cost per week
1 Loader operator 60 hrs/wk @ $3.10/hr.	
$3.10 x (40 + 30) =	$217.00
1 Attendent $2.50/hr x 70 =	175.00
Supervision (estimated)	75.00
	$467.00
Add 10% for SS, Health Ins. and Pension fund	46.70
Total	$513.70

Ditching costs for all 3 county landfills is $10,000/yr. $10,000/52 =	$192.30
Ditching cost at Kate Wagoner based on ratio of tonnage input to county total $192.20 x 40% =	$ 76.92

Equipment Maintenance Cost

Cost of equipment maintenance for 1 year = $28,997.80 or $28,997.80/52 =	$557.65/wk.
Cost of equipment maintenance based on landfill input ratio = 557.65 x.40 =	$223.06/wk.

Operation Costs

	Cost per week
Equipment capital charge	$ 96.15
Labor	513.70
Equipment maintenance and repairs	223.06
Ditching	76.92
Total landfill operation cost	$909.83

Unit Cost = $\frac{\$909.83}{360}$ = $2.53/Ton @ 60 Ton/day

CALCULATION OF LANDFILL OPERATION COSTS IN THE BALTIMORE REGION

HODGES LANDFILL - CARROLL COUNTY

Equipment Cost

1 Front end loader Caterpillar 951B	$25,000
Cost of equipment based on 5 yr. life 25,000/(52 x 5)=	$ 96.15/wk.

Labor Cost

1 Front end loader operator @$3.00/hr.	
60 hrs/wk = 40 + 30 = 70 OT	$210.00/wk.
1 Landfill attendant @$2.50/hr.	
60 hrs/wk = 40 + 30 = 70 hrs.	$175.00
Supervision (estimated)	75.00
	$460.00
Add 10% for SS, Health Ins. and Pensions	46.00
Total Labor Cost	$506.00/wk.

Cost of Equipment Maintenance

Based on input ratio = 557.65 x 1/3 =	$185.88/wk.
Ditching costs $192.20 x 1/3 =	$ 64.07/wk.

Estimated input to Hodges Landfill = 300 Tons/wk.
= 50 Tons/day = 33 1/3% of total of all
3 county landfills

Operation Costs	Cost per week
Equipment capital charge	$ 96.15
Labor	506.00
Equipment maintenance and repairs	185.88
Ditching	64.07
	$852.10

Unit cost = $\frac{\$852.10}{300\text{ T}}$ = $2.84/Ton at 50 Tons/day

CALCULATION OF LANDFILL OPERATION COSTS IN THE BALTIMORE REGION

BARKHILL LANDFILL - CARROLL COUNTY

Equipment Cost

1 Front end loader Caterpillar 951B	$25,000
Cost of equipment based on 5 yr life 25,000/(52 x 5)	$ 96.15/wk.

Labor Cost	Cost per week
1 Front end loader operator @$3.00/hr.	
60 hrs/wk = 40 + 30 OT = 70 hrs	$210.00
Supervision (estimated)	75.00
	$285.00
Add 10% for SS, Health Ins. & Pensions	28.50
Total Labor Cost	$313.50

Cost of Equipment Maintenance

Based on input ratio 40/150 = 26.7%	
.267 x $557.65 =	$208.86/wk.

Ditching costs $192.20 x .267 =	$ 51.32/wk.

Operation Costs	Cost per week
Equipment	$ 96.15
Labor	313.50
Maintenance of equipment and repairs	208.86
Ditching	51.31
Total cost of operation of Barkhill Landfill	$668.83

Estimated input to landfill = 240 Tons/wk. = 40 Tons/day

Unit Cost = $\frac{\$668.83}{240\ T}$ = $2.79/Ton at 40 Tons/day

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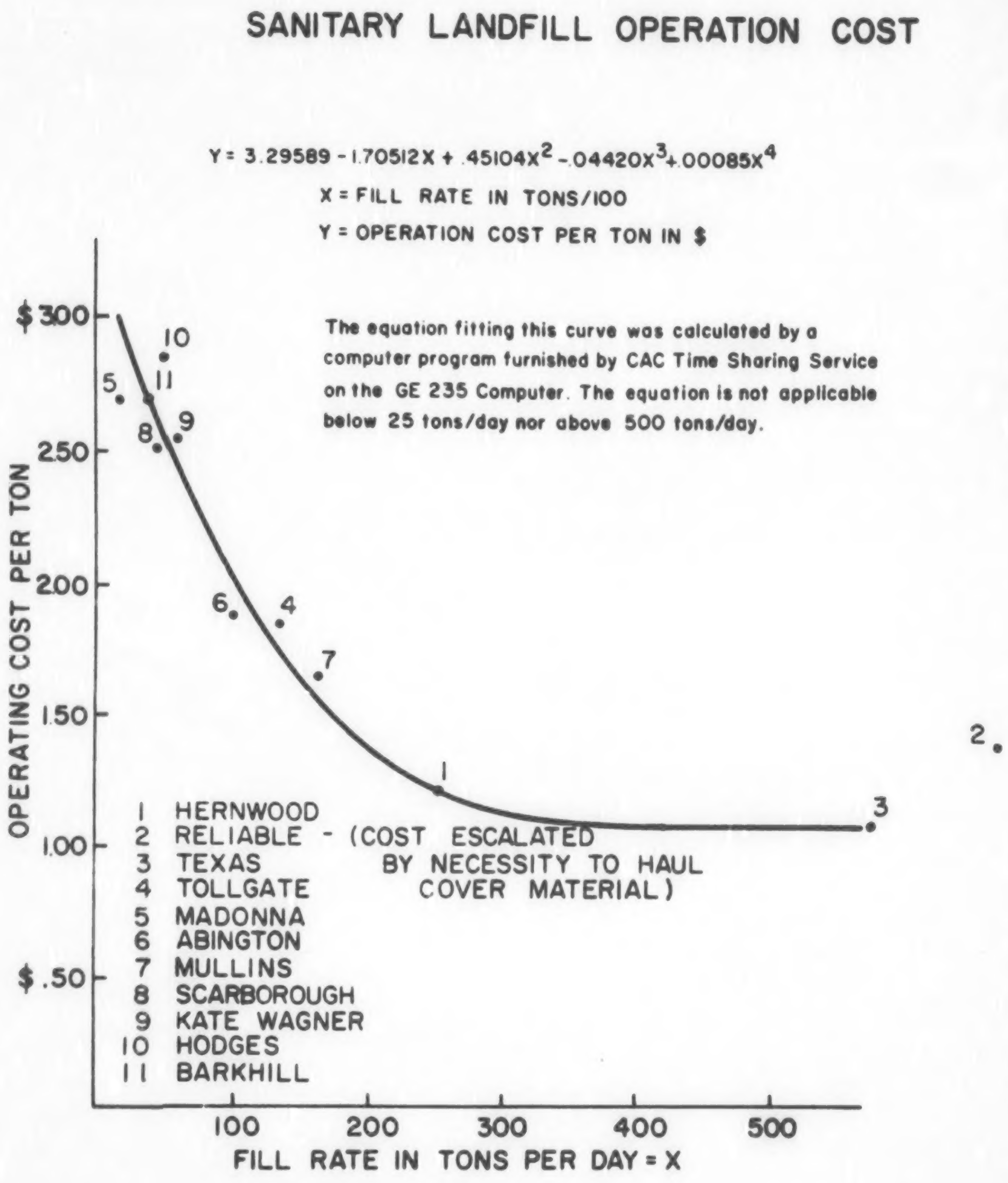

SANITARY LANDFILL OPERATION COST

$Y = 3.29589 - 1.70512X + .45104X^2 - .04420X^3 + .00085X^4$

X = FILL RATE IN TONS/100

Y = OPERATION COST PER TON IN $

The equation fitting this curve was calculated by a computer program furnished by CAC Time Sharing Service on the GE 235 Computer. The equation is not applicable below 25 tons/day nor above 500 tons/day.

1 HERNWOOD
2 RELIABLE - (COST ESCALATED BY NECESSITY TO HAUL COVER MATERIAL)
3 TEXAS
4 TOLLGATE
5 MADONNA
6 ABINGTON
7 MULLINS
8 SCARBOROUGH
9 KATE WAGNER
10 HODGES
11 BARKHILL

$3.00
2.50
2.00
1.50
1.00
$.50
OPERATING COST PER TON
100
200
300
400
500
FILL RATE IN TONS PER DAY = X
1
2
3
4
5
6
7
8
9
10
11

FIGURE 9

XIV. REFUSE DISPOSAL TRANSFER STATION AND TRACTOR TRAILER HAUL COSTS

Where transfer stations are used as an intermediate between the route collection truck and the final disposal site, the cost of transfer of the refuse, transportation to the final site and disposal is calculated on a cost per ton basis and substituted into the Solid Waste Transportation and Disposal Model as a fixed cost per ton. It was decided to handle this cost in this way in order to avoid a proliferation of data input complexities into the model.

As an aid in the calculation of this cost a set of straight lines was constructed on a graph (Figure 10). A 500 ton per day capacity transfer station was used to construct the cost graphs.

The straight line cost graph for the cost of operation of the 17 ton tractor trailer was based on the following assumptions:

Operation = \$8.40/hr. plus \$.21/mile
Loading and unloading time = 30min./trip

Based on these costs a 20-mile round trip assuming an average speed of 30 m.p.h. would cost:

$$\left[\frac{20}{30} + .5\right] \$8.40/\text{hr.} = \$9.83$$

$$20 \text{ miles} \times \$.21/\text{mile} = \underline{4.21}$$

$$\text{Total cost per trip} = \$14.04$$

$$\text{Cost per ton} = \frac{\$14.04}{17} = \$.83$$

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Using the same method of calculation a 40 mile round trip would cost \$1.35/ton. Seventeen tons are assumed to be the highway load limit regardless of the cubic yard trailer capacity.

The straight line graph for the cost of operation of the 500 ton per day transfer station is the sum of the cost values of operating the tractor trailer plus \$2.12 per ton to operate the transfer station. The cost of the transfer station operation is based upon an unofficial quotation by the Heil Equipment Company dated March 12, 1971. The cost includes capital, labor and maintenance costs for operating a 500 ton per day transfer station.

The straight line cost graph for the 20 cubic yard packer has been shown, so that a comparison can be made to shorter haul transportation not using a transfer station. This cost curve is based upon the 1971 Baltimore cost of operating a 20 cubic yard packer @ \$5.15 per hour plus one driver @ \$3.18 per hour and two loaders @ \$3.00 per hour, or a total of \$14.33 per hour. The cost of a 20-mile round trip would then be at 30 mph speed and a 12 minute unloading time,

$$\$14.33\left[\frac{20}{30} + .20\right] = \$12.47$$

$$\text{Cost per ton} = \frac{12.47}{4} = \$3.12$$

By the same method of calculation the cost of a 40-mile round trip would be \$5.48 per ton. The cost advantage shifts to the transfer station when the round trip is over 15 miles.

The total fixed cost per ton from the transfer station to final disposal would be the sum of the transfer station operation cost, the tractor trailer operation cost, the operation cost of the landfill or other disposal methods, and the land cost. This would be considered fixed at the operation capacity of the transfer station, 500 tons per day. The model would add this cost to the various transportation costs from the zones to calculate the total cost per ton.

REFUSE DISPOSAL TRANSFER STATION AND TRACTOR TRAILER HAUL COST ANALYSIS

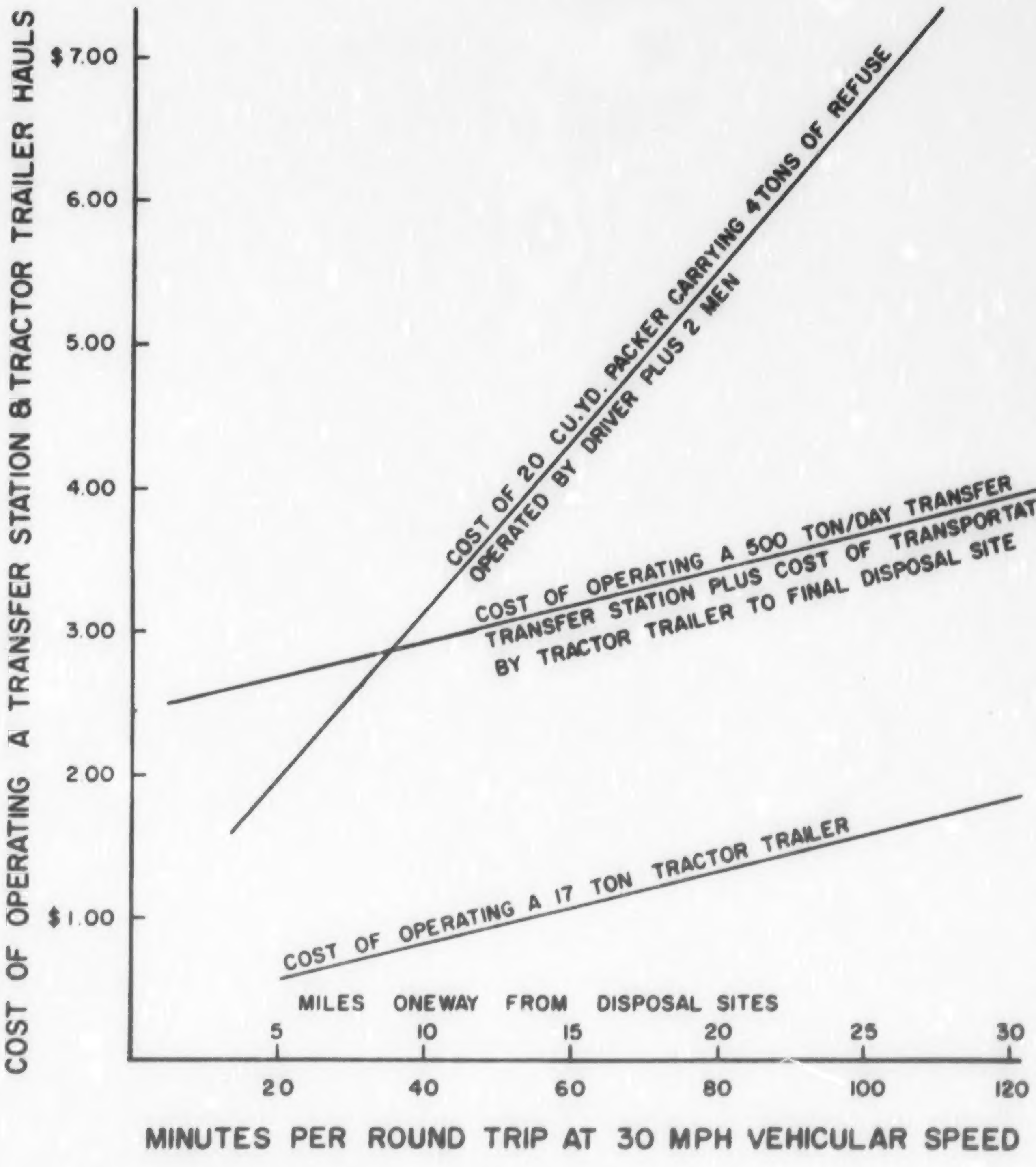

FIGURE 10

XV. MODEL TEST RUNS USING VARIOUS DISPOSAL SITE LOCATIONS IN THE BALTIMORE REGION

Before any basic cost analysis study was done to determine actual landfill operation costs in the Baltimore Region, ten computer runs were made using the model, testing combinations of different disposal site locations in Baltimore City and Baltimore County. A landfill cost of operation curve was used for these runs. This was obtained from a report written by Black and Veach for the Washington Metropolitan Region dated October 1967. Later investigation of costs in the Baltimore Region indicated that this curve underestimated costs for 1971 by about 25%.

A refuse generation curve was used for the first ten runs that was taken from Public Works Magazine dated February 1970. This was a graph of waste production in lbs. per capita per day versus residential gross population density. This curve was later found to be unrepresentative of the Baltimore Region. It overestimated domestic refuse generation by about 65% and indicated a bias toward greater generation in areas of high population densities. This overestimation of generation rate and underestimation of landfill operation costs was applied to all ten runs. This was the only data available at this time. While these runs were being made the price that Baltimore City charged private haulers for incineration was increased from $3.40 to $4.82 per ton.

Tables 3 to 12 in this section contain the results of the first ten runs. Each run is represented by a location map of the sites, a table of calculated results, and remarks pertaining to each run.

Another run of the sample problem was made to test the effect of changing the disposal site costs on the service areas of each disposal site. In the test all disposal costs were set to zero and the TRANUV program run in the balanced mode. It was found that there was no change in the disposal

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service areas. In the unbalanced mode the result would be different. Refuse would be assigned to the lowest cost location until its total capacity was exceeded, and thereafter the refuse would be assigned to the next cheapest site. Tonnage would be assigned to each cheapest site in turn until its established input acceptance rate was fulfilled. After this, surplus high cost tonnage over the total tons generated by the zones would be assigned to a meaningless dummy location.

Computer runs No. 11 and 12 were made using a fixed generation rate and an updated cost of landfill operation curve. Attempting to calculate any kind of contemporary cost is like shooting at a moving target. Reinvestigations must be made periodically and cost curves rewritten. Only by so doing can the sententious computer saw, "garbage in equal garbage out" be avoided.

Runs 13, 14 and 15 were made to demonstrate the economy of scale of landfill capacity. Eight landfill sites in the region were selected instead of the 23 which were chosen in the sample problem of the existing system. All of the sites selected were outside of Baltimore City. All sites are existing locations of landfills, but the landfill capacities are enlarged. Each site was assigned a capacity of 1,600,000 tons, allowing each location to have a life of 13.8 years, provided that each landfill has an input of 1/8 of the total regional refuse generated. Other input data to the TRIPUT program on Run No. 13 were the same as those used in the sample problem. After the TRIPUT program calculated the supplies, demands and unit costs, and stored them in the TDUMP file, each of the 8 disposal site inputs was changed (surplused) by the @ED routine to 3000 tons per week. After this adjustment the TRANUV program was run through to solution. This adjustment in the disposal site inputs placed an upper limit of 3000 tons per week on each location, and created a regional landfill input surplus of 24,000 minus 17,781 or 6219 tons. By so doing the TRANUV program assigned the tonnage to the lowest cost sites until all of the generated tons were assigned, then the remaining tons were assigned to a meaningless dummy site of higher cost. These latter assignments are allowed to be lost in the computer and only the balanced assignments appear in the printout.

Directed by the TRANUV program, the computer reassigned the tonnage and printed it at the end of run No. 13. The reassigned landfill inputs causes the operating costs of the landfills to be changed, since these unit costs are a function of the landfill inputs as determined by the curve of Figure 9. To correct for this discrepancy new landfill input percentages were calculated, and corrections made to the B cards of the TRIPUT input cards. Then the problem was rerun, and designated as Run No. 14.

Run No. 14 was handled in the same way as Run No. 13. At the end of the TRIPUT program and after the TDUMP file was created, each disposal site was assigned a 3000 ton per week input. Again the TRANUV program made a reassignment of tonnage based on recalculated landfill operation costs, and once again the new landfill input tonnages caused a change in the landfill operating costs. So the landfill percentage inputs were again changed and run No. 15 made.

The TRANUV program in Run No. 15 was run in the balanced mode and the output calculations accepted as final. Run No. 14 compared with Run No. 13 caused only a difference of +1.3% in the total final cost, and Run No. 15 caused only an additional change of + .3%. This is the extent of the correction necessary caused by introducing this nonlinear function into the Transportation Linear Program.

Table No. 15 is a copy of the printer output generated by the TRIPUT program in Runs No. 13, 14 and 15. This table shows how the regional percentage input was adjusted at the end of Runs No. 13 and 14 and how the landfill operation unit cost changed with each readjustment.

Table No. 16 is a recapitulation of the final output costs from Runs 13, 14 and 15. It shows how the tonnage is reassigned and costs changed when there is a surplus of capacities at the sites. If the lowest cost sites had been permitted to have a larger input than 3000 tons per week and the total capacity could be extended at will, a lower cost solution could be found, and probably some sites eliminated.

The input capacity of the landfills was limited for practical reasons. First, it is the opinion of local sanitation officials that a disposal site which has an input of more than 500 tons per day is apt to cause greater criticism, because of the additional truck traffic. Second, there are no landfills in the Baltimore Region that have greater inputs than this rate, therefore we do not have cost figures for these larger operations. Third, the curve constructed from existing data indicates that the cost of the operation of the landfill flattens beyond 500 tons per day input; any further increase in input would do little to lower operating costs.

The total cost of transportation and disposal calculated by the sample problem using 23 sites of various inputs and capacities was $94,981. Runs No. 13, 14 and 15 show that it would be possible to choose fewer sites and operate at lower cost. Of course, some of the difference in cost could be attributed to the high cost of incineration at two sites in the sample problem. On the other hand most of the landfills in the sample problem operated at lower inputs associated with higher unit operation costs.

There are so many variables in the solution of the Transportation and Refuse Disposal Cost Model, that it is difficult to make general statements. Best results using the model will be obtained by comparing specific cases of practical interest.

RUN NO. I BALTIMORE COUNTY

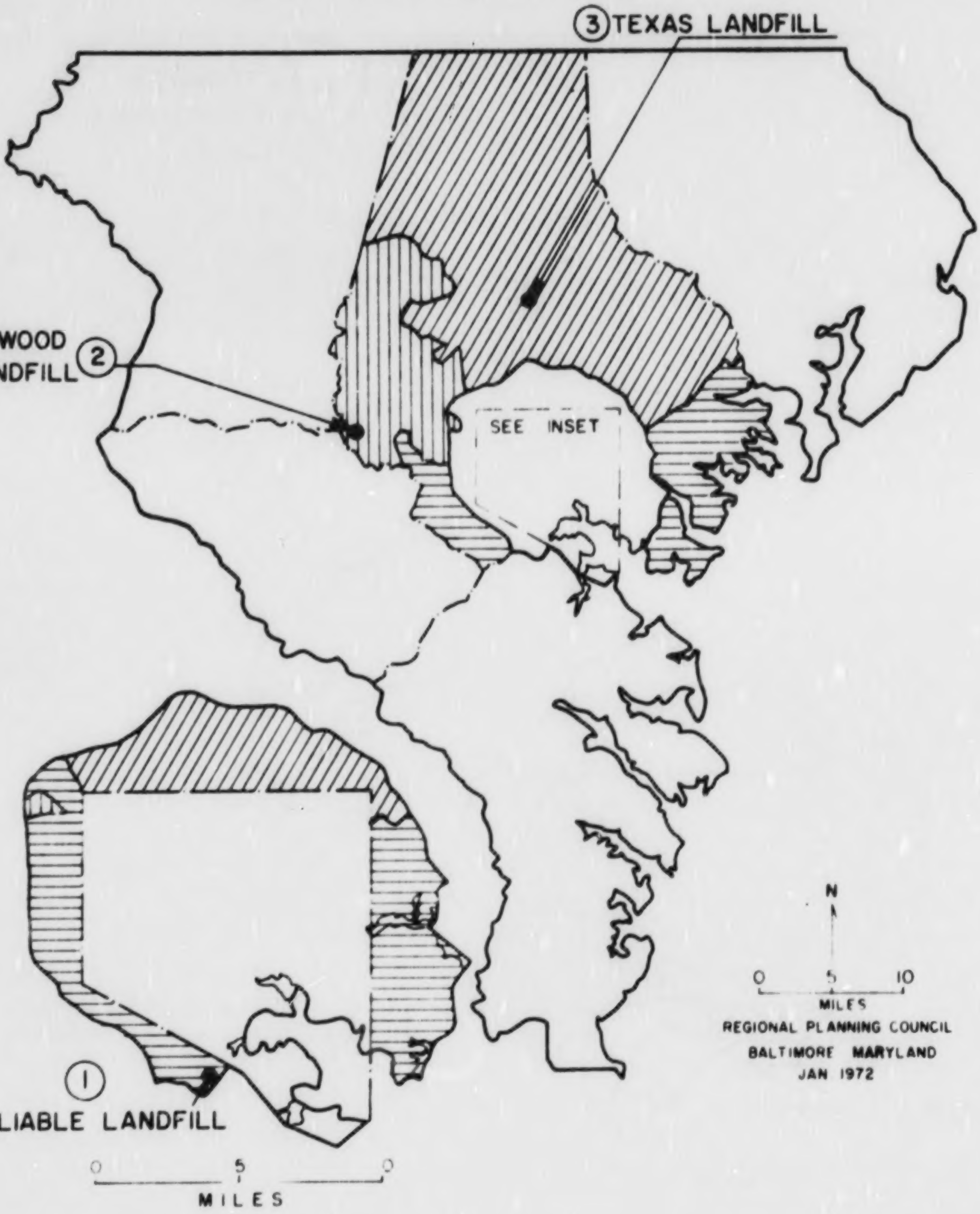
③ TEXAS LANDFILL
ERNWOOD ② LANDFILL
SEE INSET
① RELIABLE LANDFILL
0 5 0
MILES
N
0 5 10
MILES
REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND
JAN 1972

FIGURE 11

RUN NO. 2 BALTIMORE COUNTY

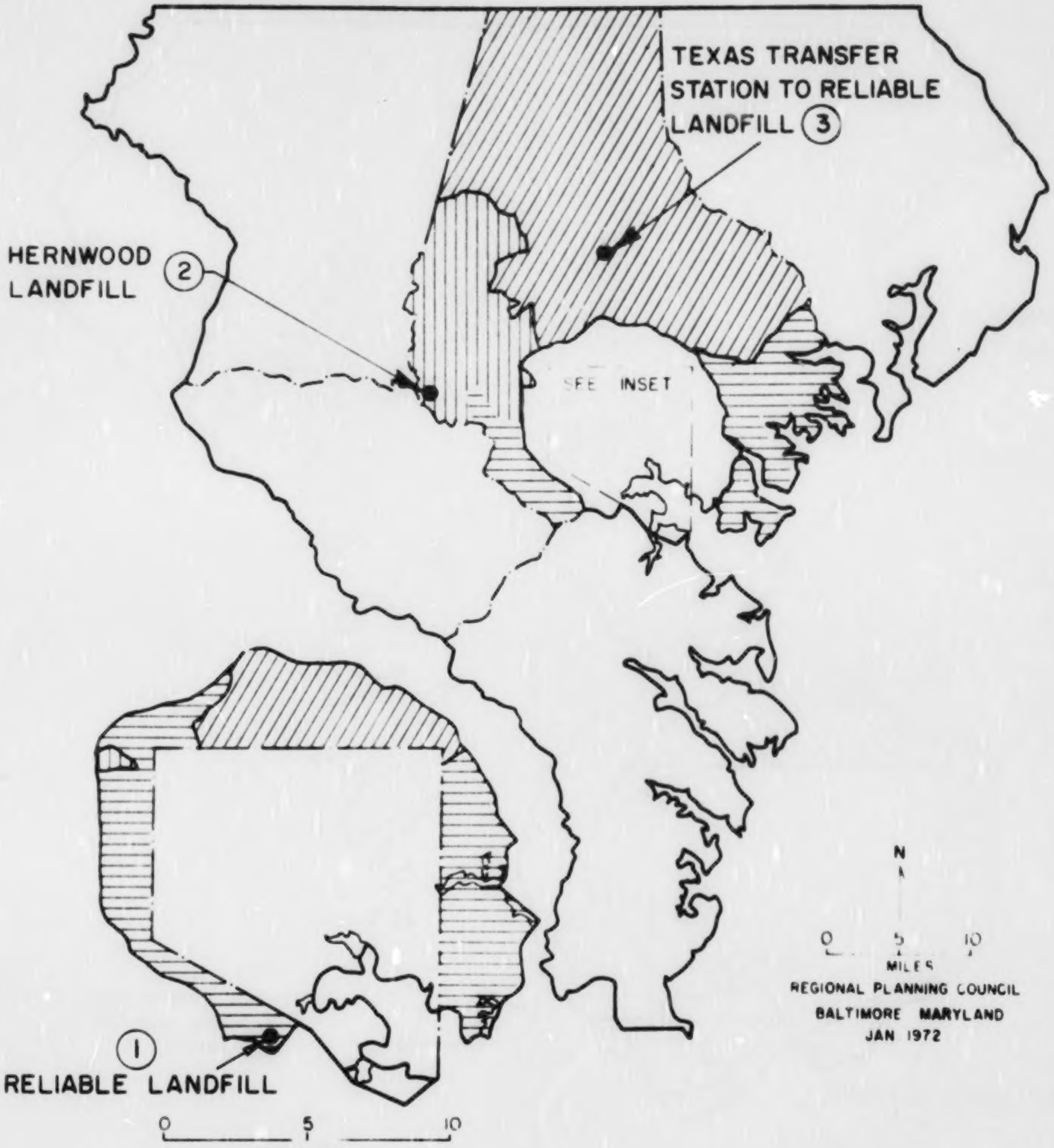
TEXAS TRANSFER STATION TO RELIABLE LANDFILL ③
HERNWOOD LANDFILL ②
SEE INSET
① RELIABLE LANDFILL
0
5
10
MILES
N
0
5
10
MILES
REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND
JAN 1972

FIGURE 12

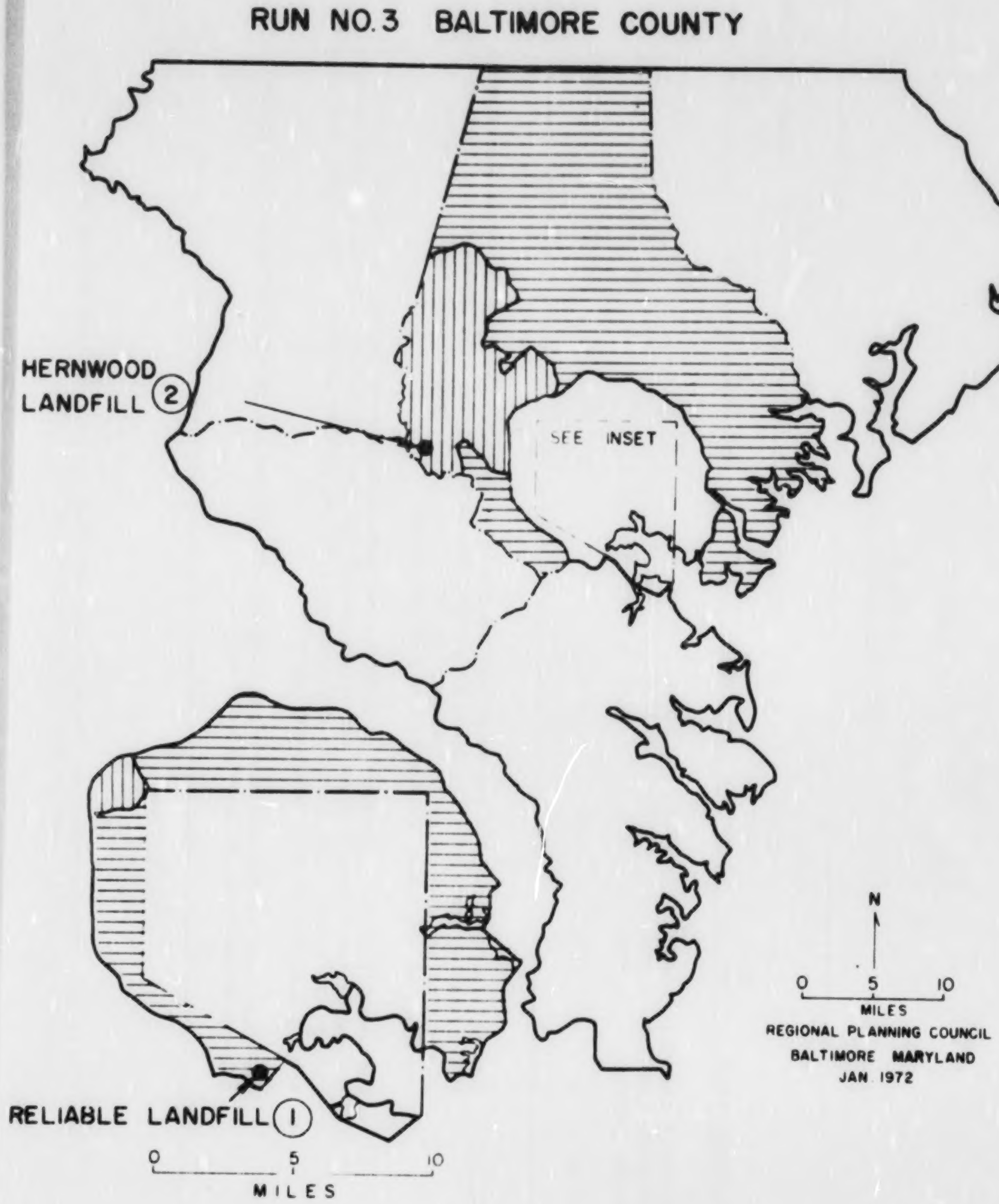
RUN NO.3 BALTIMORE COUNTY
HERNWOOD LANDFILL ②
SEE INSET
N
0 5 10
MILES
REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND
JAN. 1972
RELIABLE LANDFILL ①
0 5 10
MILES

FIGURE 13

TABLE 3

RUN NO. 1
BALTIMORE COUNTY ONLY

	DISPOSAL SITES	INPUT TONS PER WK.	INPUT TONS PER DAY	% OF TOTAL GENERATED	DISPOSAL COST PER TON	AVG. TRANS-PORTATION & DISPOSAL COST/TON	ESTIMATED REMAINING CAPACITY TONS	TOTAL SITE TRANSPORTATION AND DISPOSAL COST*
1.	RELIABLE LANDFILL	4843	807	55.4	$2.66	$5.67	800,000.	$27,466.
2.	HERNWOOD LANDFILL	1004	167	11.5	1.84	3.71	52,000.	3,731.
3.	TEXAS LANDFILL	2889	482	33.1	3.02	5.01	100,000.	14,524.
	TOTAL	8736	1456	100.0		5.23	952,000.	$45,721.

REMARKS: This Baltimore County Run was an attempt to simulate inputs to the disposal sites according to 1970 operating practice. The areas of service for each disposal site represent the optimum cost at the tons per week operating rate of the landfills. This optimum cost could be lowered, if the input of the lowest cost site could be increased.

The computer is not programmed to indicate how much tonnage goes through the harbor tunnel. The transportation vehicular times are selections of the shortest routes. If the shortest route is through the tunnel, than that is the route used in the problem solution. The tunnel toll charges are not included in the transportation cost.

The total cost of transportation and disposal of this run can be used for comparison to costs calculated for other disposal site plans.

---

*Total site transportation and disposal cost includes the cost of land and equipment, but not interest on capital, and no on route collection costs.

TABLE 4

RUN NO. 2
BALTIMORE COUNTY ONLY

	DISPOSAL SITE	INPUT TONS PER WK.	INPUT TONS PER DAY	% OF TOTAL GENERATED	DISPOSAL COST PER TON	AVG. TRANSPORTATION & DISPOSAL COST/TON	ESTIMATED REMAINING CAPACITY TONS	TOTAL SITE TRANSPORTATION AND DISPOSAL COST*
1.	RELIABLE LANDFILL	5284	881	60.5	$2.66	$5.73	800,000	$30,286.
2.	HERNWOOD LANDFILL	1004	167	11.5	1.84	3.73	52,000.	3,750.
3.	TEXAS TRANSFER STATION	2448	408	28.0	4.19	6.03	---	14,981.
	TOTALS	8730	1456	100.0		5.61	852,000.	$49,017.

REMARKS: This run simulates the situation that occurs when the Texas Landfill has been depleted, and no other disposal site has been obtained. In this case only two disposal sites remain and a transfer station is set up at the site of the Texas depleted landfill. The cost of transferring the refuse from the Texas Transfer Station to Reliable has been assumed to be $1.53 per ton.

Off route transportation plus site disposal under this plan would cost $3296. per week more than that used for RUN NO. 1 or $171,392 more per year.

*Total site transportation and disposal cost includes the cost of land and equipment, but no interest on capital, or on route collection costs.

TABLE 5

RUN NO. 3
BALTIMORE COUNTY ONLY

	DISPOSAL SITES	INPUT TONS PER WK.	INPUT TONS PER DAY	% OF TOTAL REFUSE GENERATED	DISPOSAL COST PER TON	AVG. TRANSPORTATION DISPOSAL COST/TON	ESTIMATED REMAINING CAPACITY TONS	TOTAL SITE TRANSPORTATION AND DISPOSAL COST*
1.	RELIABLE LANDFILL	7700	1284	88.15	$2.66	$6.11	800,000.	$47,047.
2.	HERNWOOD LANDFILL	1036	172	11.65	1.84	3.73	52,000.	3,871.
	TOTALS	8736	1456	100.0		$5.82	852,000.	$50,918.

REMARKS: This run simulates a condition in Baltimore County when the Texas Landfill has been depleted and a transfer station at this site has not been built. Under this condition it would be necessary to send the refuse collection trucks directly to either Reliable or Hernwood Landfills.

The cost of disposal and transportation in this case would be $5197 more per week and $260,244 per year more than that for RUN No. 1 representing conditions existing in 1970.

The additional cost over that simulated by RUN No. 2 where a transfer station would be built at Texas would be $1901 per week or $98,852 per year.

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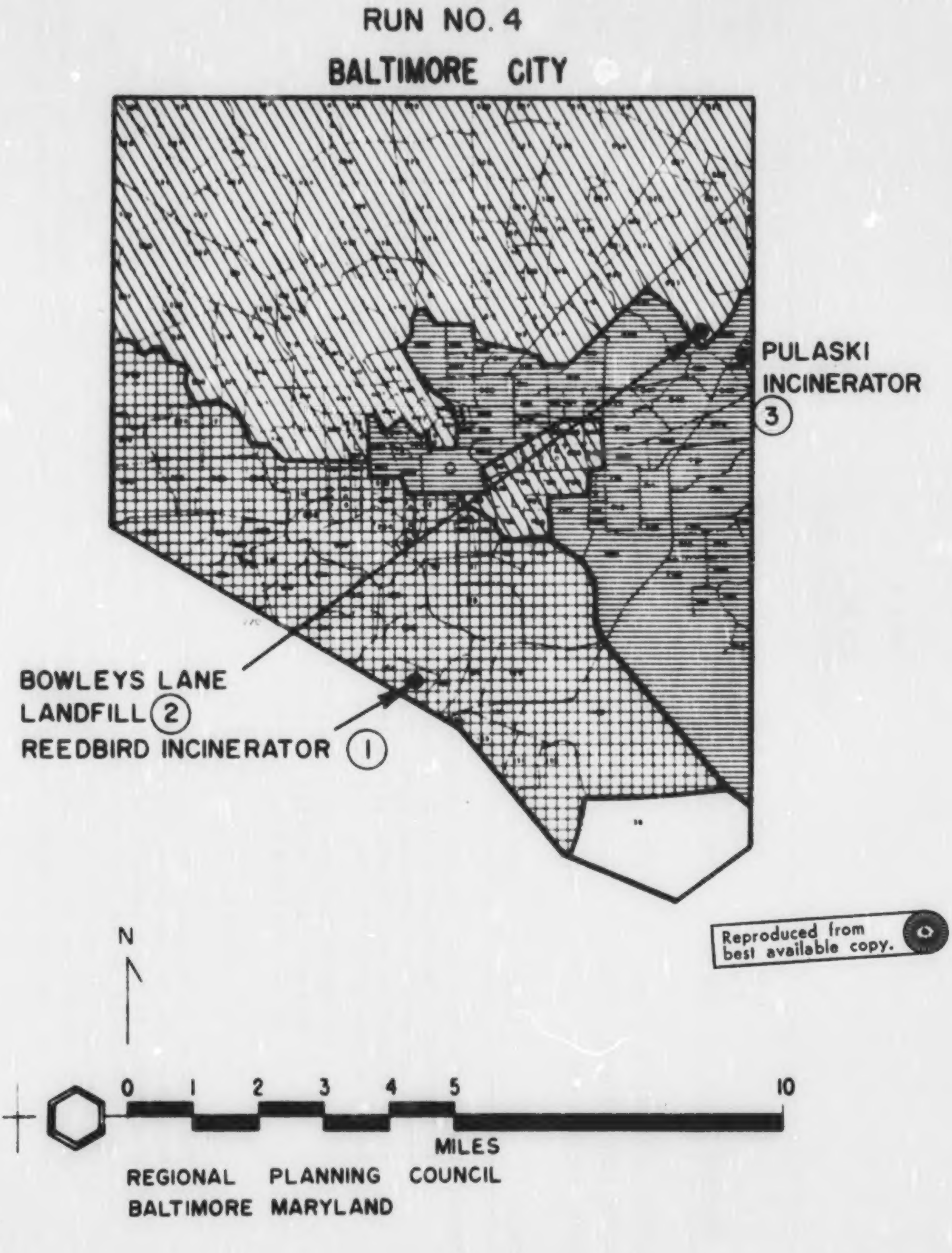
*The total cost of transportation and disposal includes the cost of land and equipment, but no


RUN NO. 4
BALTIMORE CITY
PULASKI INCINERATOR ③
BOWLEYS LANE LANDFILL ②
REEDBIRD INCINERATOR ①
N
0 1 2 3 4 5 10
MILES
REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND

Reproduced from best available copy.

FIGURE 14

TABLE 6

RUN NO. 4
BALTIMORE CITY ONLY

	DISPOSAL SITES	INPUT. TONS PER WK.	INPUT TONS PER DAY	% OF TOTAL REFUSE GENERATED	DISPOSAL COST PER TON	AVG. TRANS-PORTATION DISPOSAL COST/TON	ESTIMATED REMAINING CAPACITY TONS	TOTAL SITE TRANSPORTATION AND DISPOSAL COST*
1.	REEDBIRD INCINERATOR	4083	680	30.0	$4.57	$5.95		$16,647.
2.	BOWLEYS LANE LANDFILL	1361	227	10.0	3.00	4.77		24,908.
3.	PULASKI INCINERATOR	8167	1361	60.0	4.82	6.86		38,446.
	TOTALS	13611	2268			$5.87		$80,002.

REMARKS: Due to the fact that the above actual percentages of total refuse (cols. 1 & 2) overload the incinerators, the percentages of refuse to each site was readjusted, so that the input to the incinerators would not overload them. The following distribution was then made to hold the incinerators at Reedbird and Pulaski within their capacities. The excess of refuse was diverted to the Bowley's Lane Landfill. This, of course, is a greater amount than is actually sent here.

Reedbird Incinerator	2794	Tons	20.6%
Bowley's Lane Landfill	5213	"	38.3%
Pulaski Incinerator	5604	"	41.1%
Totals	13,611		100.0%

The tons of refuse generated by the computer from the population zones seems to be greater than is being sent to the two incinerators and Bowley's Landfill. This may be accounted for by the fact that refuse is being taken directly to Reedbird Landfill adjacent to the incinerator, the Green Spring Landfill and to landfills owned by private haulers. None of these mentioned disposal sites are accounted for by this run, and these unknown flows all end up as surplus at Bowley's Lane, a situation which does not fit reality. The amount of tonnage going to these unaccounted for locations is not known, so that a balance cannot be made between the amount of refuse generated and that disposed.

---

*Total site transportation and disposal cost includes the cost of land and equipment, but no interest

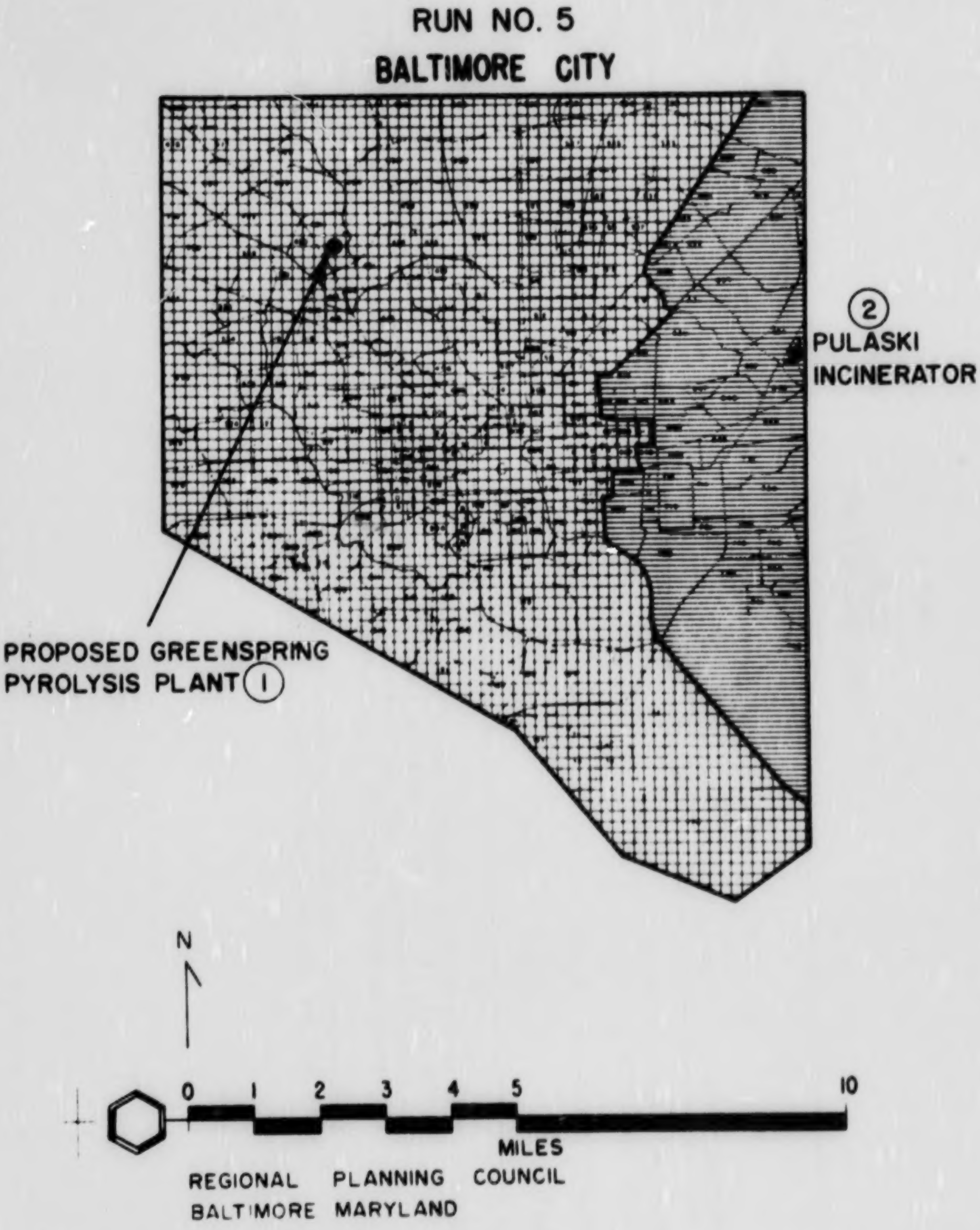

RUN NO. 5
BALTIMORE CITY
②
PULASKI
INCINERATOR
PROPOSED GREENSPRING
PYROLYSIS PLANT ①
N
0 1 2 3 4 5 10
MILES
REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND

FIGURE 15

TABLE 7

RUN NO. 5
BALTIMORE CITY ONLY

	DISPOSAL SITES	INPUT TONS PER WK.	INPUT TONS PER DAY	% OF TOTAL REFUSE GENERATED	DISPOSAL COST PER TON	AVG. TRANSPORTATION & DISPOSAL COST/TON	ESTIMATED REMAINING CAPACITY TONS	TOTAL SITE TRANSPORTATION AND DISPOSAL COST*
1.	PROPOSED GREEN SPRING PYROLYSIS	10,807	1801	79.40	$5.90	7.40	---	$80,065.
2.	PULASKI INCINERATOR	2,804	467	20.60	4.82	6.20	---	17,406.
	TOTALS	13,611	2268	100.0		7.16		$97,471.

REMARKS: This is a simulation assuming that a pyrolysis plant will be built at Green Spring Avenue and Cold Spring Lane, the site of an existing landfill that presently accepts bulky items and street sweepings. The Reedbird Incinerator will be closed and the Pulaski Incinerator will be run at rated capacity. The remaining refuse generated in Baltimore City will be sent to the proposed pyrolysis plant.

A comparison of the cost of this operation indicates that the cost will be $17,470 per week or $908,440 per year more than the plant arrangement used in 1970 simulated by RUN No. 4.

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*Total site transportation and disposal cost includes the cost of land and equipment, but no interest on capital, and no on route collection costs.

RUN NO.6 BALTIMORE CITY AND BALTIMORE COUNTY

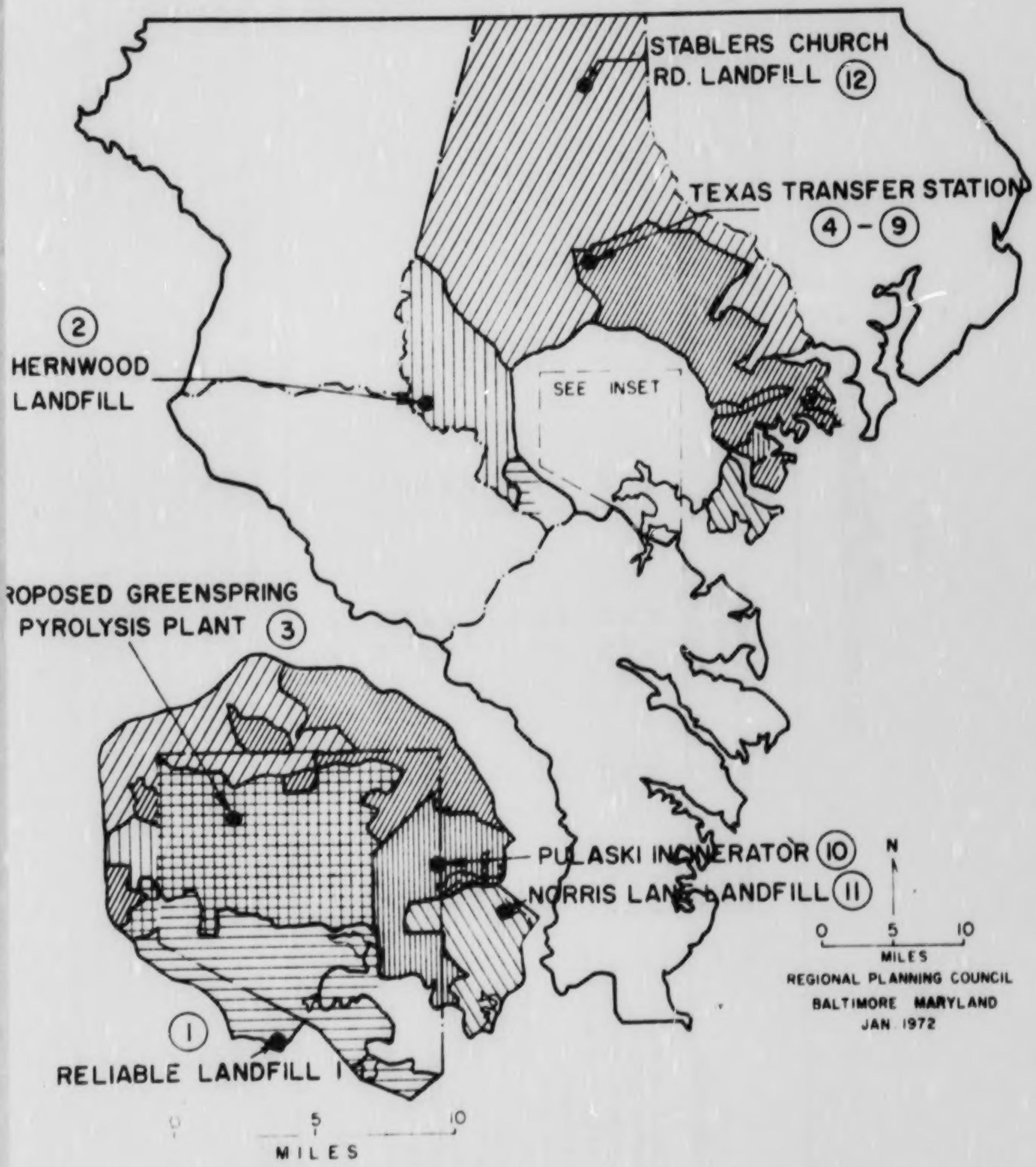

STABLERS CHURCH
RD. LANDFILL ⑫
TEXAS TRANSFER STATIO
④ - ⑨
②
HERNWOOD
LANDFILL
SEE INSET
ROPOSED GREENSPRING
PYROLYSIS PLANT ③
PULASKI INCINERATOR ⑩
NORRIS LANE LANDFILL ⑪
N
0 5 10
MILES
REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND
JAN 1972
①
RELIABLE LANDFILL I
0 5 10
MILES

FIGURE 16

TABLE 8

RUN NO. 6
BALTIMORE CITY AND BALTIMORE COUNTY

DIPOSAL SITES	INPUT TONS PER WK.	INPUT TONS PER DAY	% OF TOTAL REFUSE GENERATED	DISPOSAL COST PER TON	AVG. TRANS-PORTATION & DISPOSAL COST/TON	ESTIMATED REMAINING CAPACITY TONS	TOTAL SITES TRANSPORTATION AND DISPOSAL COST*
1. RELIABLE LANDFILL	3846	641	17.21	$2.66	$4.02	800,000	$15,475.
2. HERNWOOD LANDFILL	1000	167	4.47	1.84	3.93	52,000	3,736.
3. GREENSPRING PYROLYSIS PL.	7000	1167	31.32	5.90	7.14		50,010.
TEXAS TRANSFER STA.							
4. TO RELIABLE	960	160	4.30	4.19	7.10	---	6,823.
5. TO HERNWOOD	960	160	4.30	3.37	5.08	---	4,879.
6. TO GREENSPRING PYRO.	---		---	6.83	---	---	---
7. TO PULASKI INCINERATOR	---		---	6.35	---	---	---
8. TO NORRIS LANE	960	160	4.30	3.53	5.83	---	5,600.
9. TO STABLER'S CHURCH RD.	960	160	4.30	4.30	7.07	---	6,789.
10. PULASKI INCINERATOR	2400	400	10.74	4.82	6.14	---	14,745.
11. NORRIS LANE	1500	250	6.71	2.00	3.02	---	4,545.
12. STABLER'S CHURCH RD.	2761	460	12.35	2.50	6.01	---	21,802.
TOTAL	22347	3725	100.0				$134,403.

REMARKS: This is a simulation of a joint operation between Baltimore City and Baltimore County. A transfer station has been put at the site of the depleted Texas Landfill. The run has been setup so that refuse may be sent from the Texas transfer station to any one of 6 landfills. The result of the run indicates that no tonnage would be sent to the Green Spring Pyrolysis Plant or to the Pulaski Incinerator thru the transfer station because of the high cost. The refuse comming into the transfer station would be dispatched to Norris Lane, Hernwood, Stabler's Church Road and Reliable. This allocation of refuse is unrealistic because Reliable, Hernwood and Norris Lane would all have their input capacity exceeded. Therefore, another run must be made eliminating these alternatives. Then the choice will be made between sending refuse directly to Stabler's Church Road or via the Texas Transfer Station.

TABLE 8 (Cont'd)

This run has been set up with an upper limit of 640 tons for the transfer station. This run may be compared with RUN No. 9 where all refuse coming into the Texas transfer station goes to Stabler's Church Road.

---

*Total site transportation and disposal cost includes cost of land and equipment, but no interest on capital, and no on route collection costs.

RUN NO. 7 BALTIMORE COUNTY

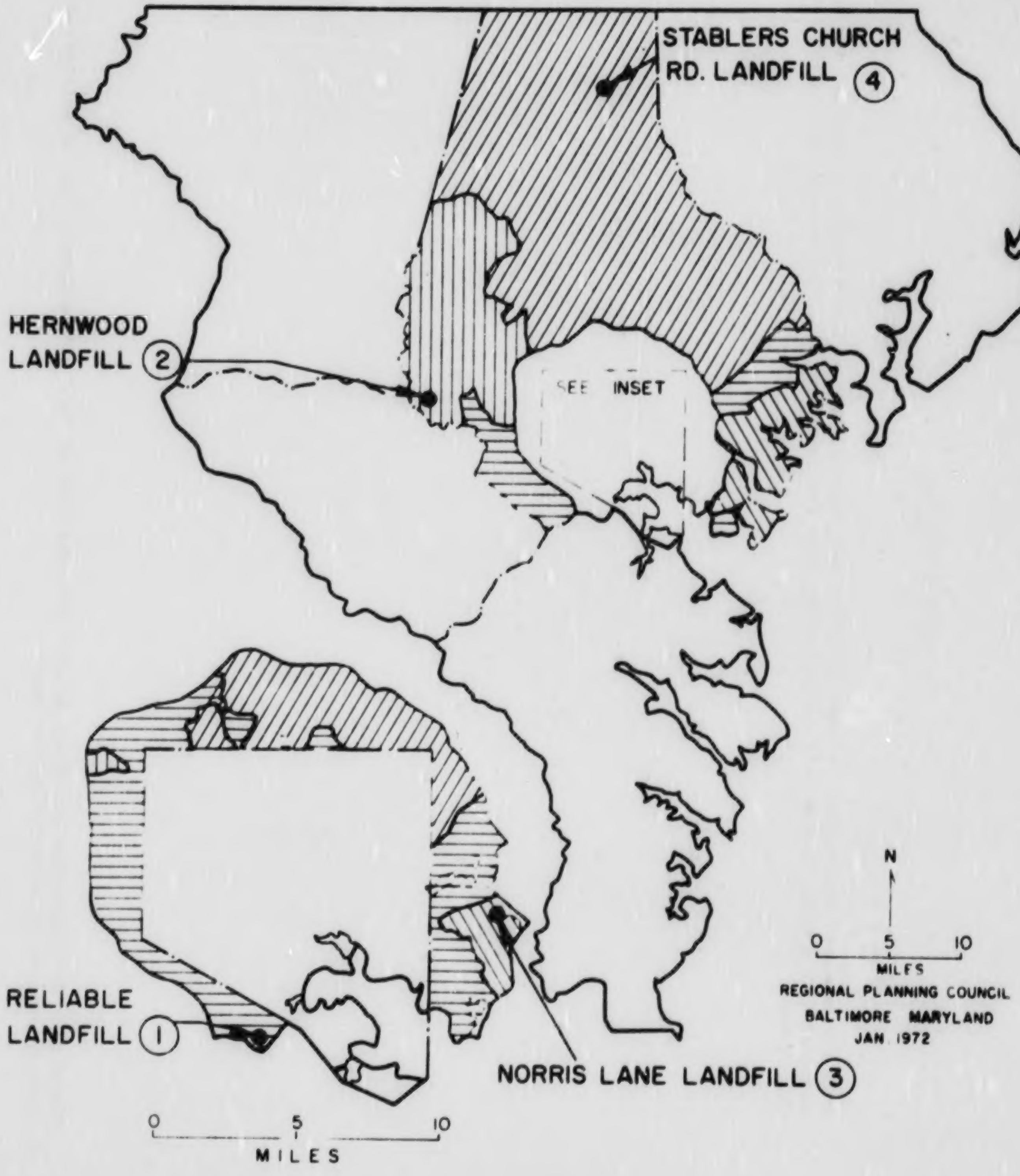

STABLERS CHURCH
RD. LANDFILL ④
HERNWOOD
LANDFILL ②
SEE INSET
RELIABLE
LANDFILL ①
NORRIS LANE LANDFILL ③
N
0 5 10
MILES
REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND
JAN. 1972
0 5 10
MILES

FIGURE 17

TABLE 9

RUN NO. 7

BALTIMORE COUNTY ONLY

	DISPOSAL SITES	INPUT TONS PER WK.	INPUT TONS PER DAY	% OF TOTAL REFUSE GENERATED	DISPOSAL COST PER TON	AVG. TRANSPORTATION & DISPOSAL COST/TON	ESTIMATED REMAINING CAPACITY TONS	TOTAL SITE TRANSPORTATION AND DISPOSAL COST*
1.	RELIABLE LANDFILL	3846	641	44.03	2.66	5.34	800,000	$20,571.
2.	HERNWOOD LANDFILL	1000	167	11.45	1.84	3.73	52,000	3,736.
3.	NORRIS LAND LANDFILL	1499	250	17.17	2.00	3.27	---	4,914.
4.	STABLER'S CHURCH RD.	2391	398	27.35	2.50	7.40	---	17,695.
	TOTAL	8736	1456	100.0		5.37		$46,916.

REMARKS: This run simulates fixed upper limits to the inputs to three landfills Reliable, Hernwood, and Norris Lane. The overflow is sent to Stabler's Church Road. If the first three landfills were not limited in input, the total cost would be lower. Because of Stabler's Church Road being a more remote location, the cost of transportation is higher for many of the zones contributing refuse to it.

No transfer station is used in this simulation.

---

*Total site transportation and disposal cost includes the cost of land and equipment, but not interest on capital, and no on route collection costs.

RUN NO.8 BALTIMORE COUNTY

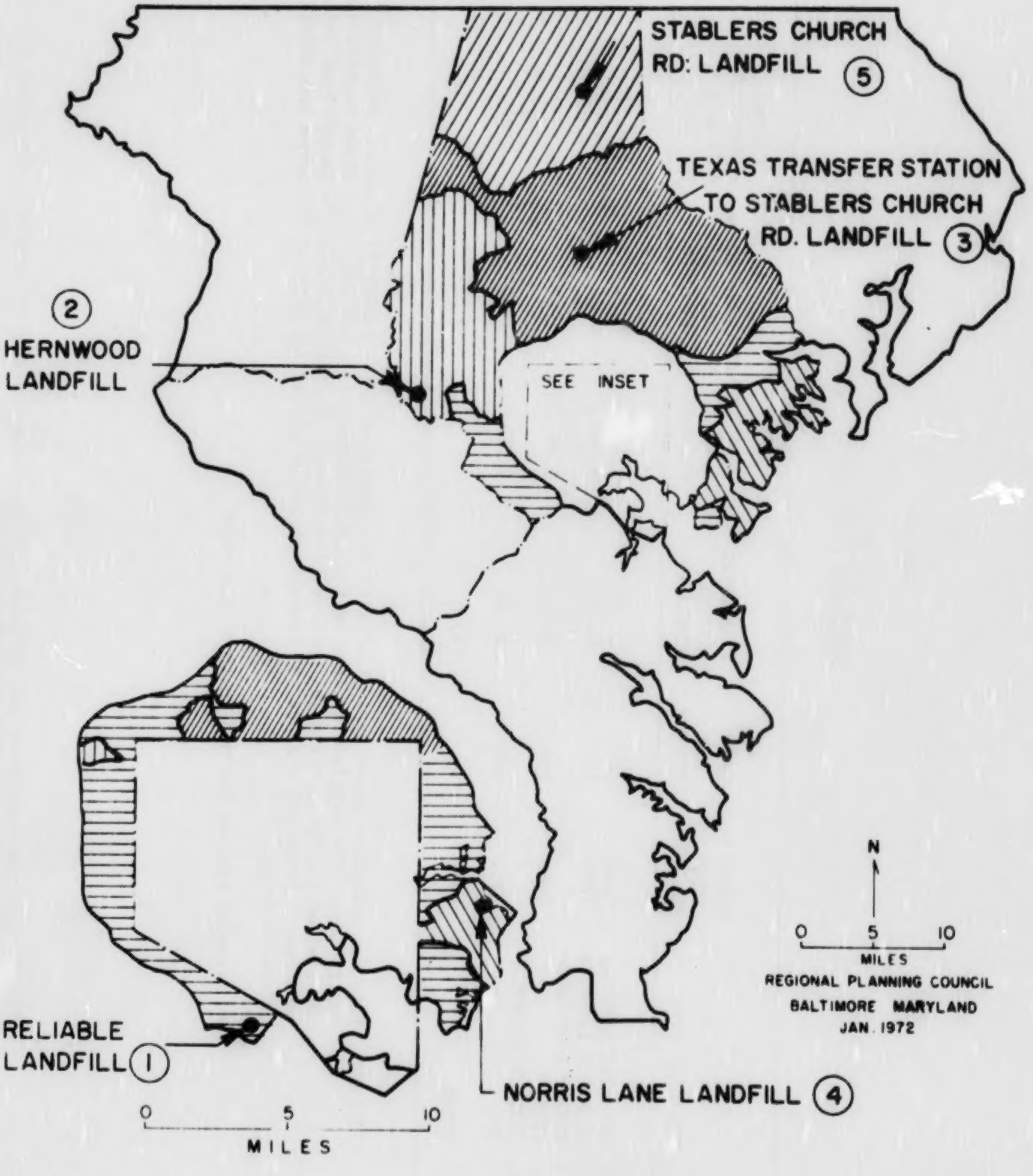

STABLERS CHURCH
RD. LANDFILL ⑤
TEXAS TRANSFER STATION
TO STABLERS CHURCH
RD. LANDFILL ③
② HERNWOOD LANDFILL
SEE INSET
N
0 5 10
MILES
REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND
JAN. 1972
RELIABLE LANDFILL ①
NORRIS LANE LANDFILL ④
0 5 10
MILES

FIGURE 18

TABLE 10

RUN NO. 8
BALTIMORE COUNTY ONLY

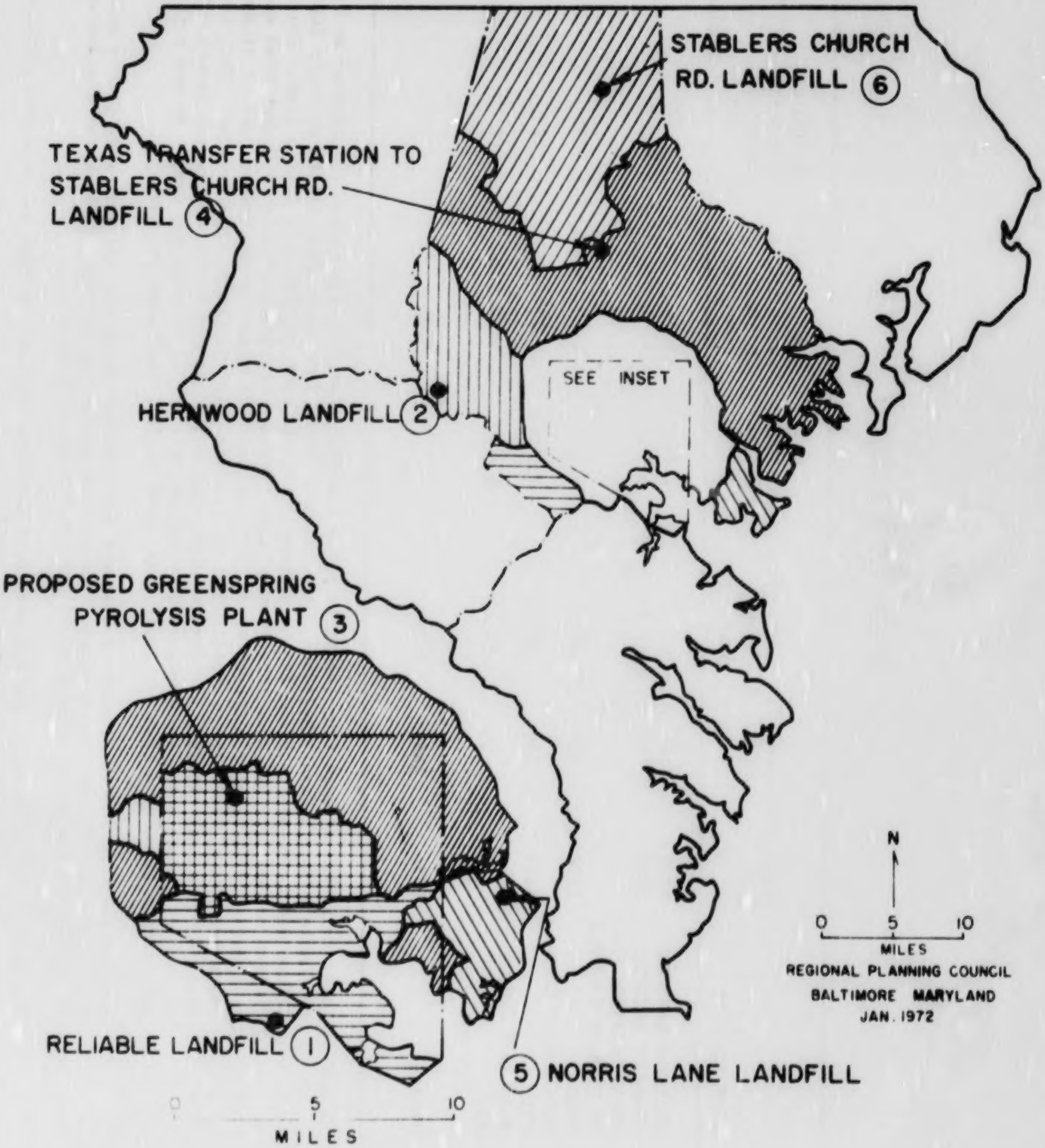
	DISPOSAL SITE	INPUT TONS PER WK.	INPUT TONS PER DAY	% OF TOTAL REFUSE GENERATED	DISPOSAL COST PER TON	AVG. TRANSPORTATION & DISPOSAL COST/TON	ESTIMATED REMAINING CAPACITY TONS	TOTAL SITE TRANSPORTATION AND DISPOSAL COST*
1.	RELIABLE LANDFILL	3846	641	44.03	2.66	5.34	800,000	$20,589.
2.	HERNWOOD LANDFILL	1000	166	11.45	1.84	3.73	52,000	3,736.
3.	TEXAS TRANSFER STA. TO STABLER'S CHURCH ROAD	2302	384	13.67	4.30	6.18	---	14,234.
4.	NORRIS LANE LANDFILL	1499	250	17.17	2.00	3.27	?	4,914.
5.	STABLER'S CHURCH RD. (DIRECT)	88	15	13.68	2.50	5.02	?	442.
	TOTALS	8736	1456	100.0		5.02		$43,915.

REMARKS: This simulation assumes four landfills and a transfer station. All refuse transferred at Texas goes to Stable's Church Road. Reliable, Hernwood and Norris Lane have upper limits on their inputs. The refuse generated over the sum of these upper limits is sent to Stabler's Church Road. The model decides how much refuse goes through the Texas Transfer Station to Stabler's Church Road and how much goes directly to Stabler's Church Road. This decision is based on the lowest cost of disposal and transportation. The optimum capacity of the transfer station is 384 tons per day. This is an average not a peak capacity and further more does not allow for future population growth. The amount of tons of refuse going to Stabler's Church Road directly is 88 tons per week. By our method of calculation allowing 4 tons per truck this would be 22 truck loads per week.

A comparision of the total cost of disposal and transportation for all Baltimore County schemes tested indicates that this is the cheapest. The cost of refuse put through the transfer station was set at $1.80 per ton for transfer plus $2.50 per ton for final disposal.

*Total site transportation and disposal cost includes the cost of land and equipment, but no interest on capital, and no on route collection costs.

RUN NO. 9 BALTIMORE CITY AND BALTIMORE COUNTY


STABLERS CHURCH RD. LANDFILL ⑥
TEXAS TRANSFER STATION TO STABLERS CHURCH RD. LANDFILL ④
SEE INSET
HERNWOOD LANDFILL ②
PROPOSED GREENSPRING PYROLYSIS PLANT ③
RELIABLE LANDFILL ①
⑤ NORRIS LANE LANDFILL
N
0 5 10
MILES
0 5 10
MILES

REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND
JAN. 1972

FIGURE 19

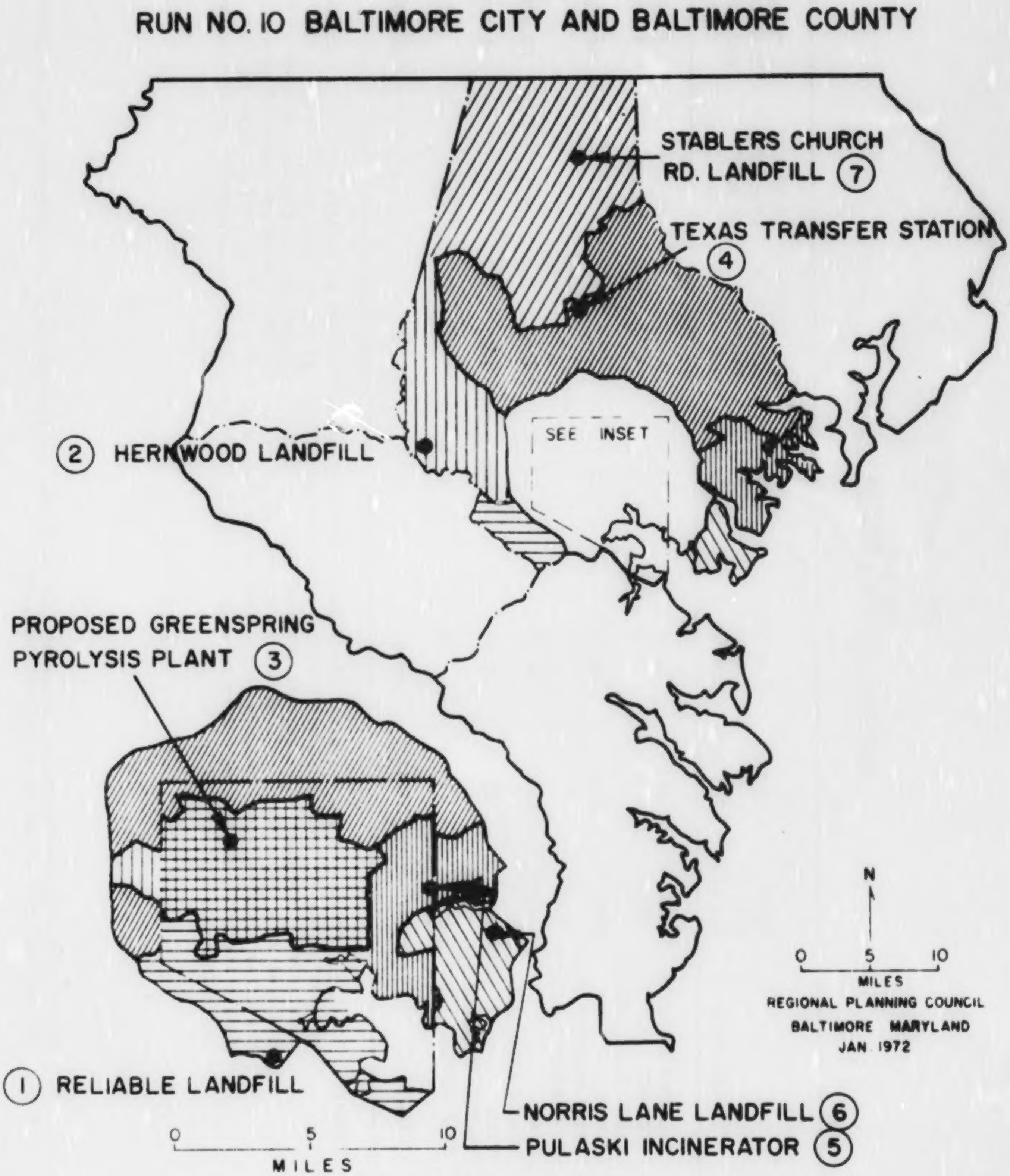
TABLE 11

RUN NO. 9
BALTIMORE CITY AND BALTIMORE COUNTY

	DISPOSAL SITES	INPUT TONS PER WK.	INPUT TONS PER DAY	% OF TOTAL REFUSE GENERATED	DISPOSAL COST PER TON	AVG. TRANSPORTATION & DISPOSAL COST/TON	ESTIMATED REMAINING CAPACITY TONS	TOTAL SITE TRANSPORTATION AND DISPOSAL COST*
1.	RELIABLE LANDFILL	3845	641	17.21	$2.66	4.05	800,000	$15,577.
2.	HERNWOOD LANDFILL	998	166	4.47	1.84	3.73	52,000	3,725.
3.	GREENSPRING PYROLYSIS PL.	6848	1141	30.64	5.90	7.19	---	49,280.
4.	TEXAS TRANSFER STA. TO STABLER'S CHURCH ROAD	9000	1500	40.27	4.30	7.02	---	63,220.
5.	NORRIS LAND LANDFILL	1499	250	6.71	2.00	3.03	---	4,546.
6.	STABLER'S CHURCH ROAD DIRECT	157	26	.70	2.50	5.43	---	853.
	TOTAL	22347	3724	100.0		6.13		$137,200.

REMARKS: In this pattern of disposal sites the Pulaski Incinerator was inadvertantly left out. The result was that a higher total cost was recorded than that of RUN No. 10 which includes the Pulaski Incinerator. This run is of academic interest because it shows the results of removing a lower cost disposal site situated in a favorable location. Upper limits of refuse acceptance placed on all the other sites except Stabler's Church Road which must accept the surplus. Due to ther latters remote location, and the necessity to ship through a transfer station causes escalation of the total cost above that of RUN No. 10.

*Total site transportation and disposal cost includes the cost of land and equipment, but no interest on capital, and no on route collection costs.


RUN NO. 10 BALTIMORE CITY AND BALTIMORE COUNTY

STABLERS CHURCH RD. LANDFILL ⑦
TEXAS TRANSFER STATION ④
SEE INSET
② HERNWOOD LANDFILL
PROPOSED GREENSPRING PYROLYSIS PLANT ③
① RELIABLE LANDFILL
NORRIS LANE LANDFILL ⑥
PULASKI INCINERATOR ⑤
0 5 10
MILES
N
0 5 10
MILES
REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND
JAN. 1972

FIGURE 20

TABLE 12

RUN NO. 10
BALTIMORE CITY AND BALTIMORE COUNTY

	DISPOSAL SITES	INPUT TONS PER WK.	INPUT TONS PER DAY	% OF TOTAL REFUSE GENERATED	DISPOSAL COST PER TON	AVG. TRANS-PORTATION & DISPOSAL COST/TON	ESTIMATED REMAINING CAPACITY TONS	TOTAL SITE TRANSPORTATION AND DISPOSAL COST*
1.	RELIABLE LANDFILL	3845	641	17.21	$2.66	4.01	800,000	$15,451.
2.	HERNWOOD LANDFILL	1001	167	4.48	1.84	3.73	52,000	3,736.
3.	GREENSPRING PYROLYSIS PLANT	6828	1138	30.55	5.90	7.12	---	48,649.
4.	TEXAS TRANSFER STA. TO STABLER'S CHURCH ROAD	5401	900	24.17	4.30	6.59	---	35,626.
5.	PULASKI INCINERATOR	3600	600	16.11	4.82	6.24	---	22,470.
6.	NORRIS LAND LANDFILL	1500	250	6.71	2.00	3.02	---	4,544.
7.	STABLER'S CH. ROAD (DIRECT)	172	28	.77	2.50	5.65	---	973.
	TOTAL	22,347	3724	100.0		5.88		$131,448.

REMARKS: This computer run delineates the savings that can be affected by combining the use of disposal sites in Baltimore City and Baltimore County. Comparison of the sum of RUN No. 5 (Baltimore City only) and of RUN No. 8 (Baltimore County only) with RUN No. 10 indicates that approximately $10,000 per week can be saved by combining the use of disposal sites.

This simulation demonstrates the wisdom of City and County joint use of disposal sites. The lower total cost occurs because of reduced travel time from the collection routes to the disposal sites.

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*Total cost of transportation and disposal includes the cost of land and equipment, but no interest on capital, and no on route collection costs.

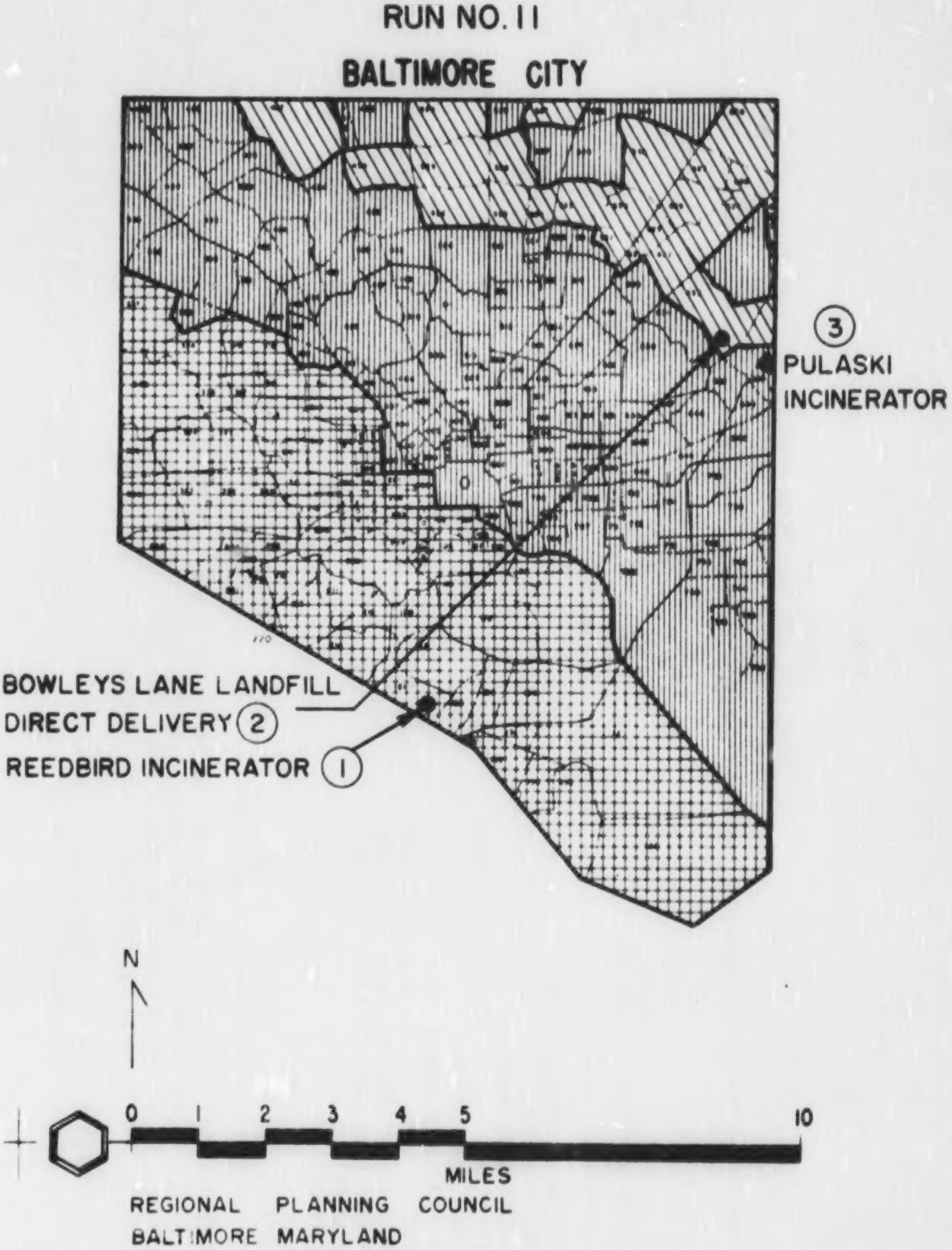
RUN NO. 11
BALTIMORE CITY
③ PULASKI INCINERATOR
BOWLEYS LANE LANDFILL
DIRECT DELIVERY ②
REEDBIRD INCINERATOR ①
N
0 1 2 3 4 5 10
MILES
REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND

FIGURE 21

TABLE 13

RUN NO. 11
BALTIMORE CITY ONLY

	DISPOSAL SITES	INPUT TONS PER WK.	INPUT TONS PER DAY	% OF TOTAL GENERATED	TOTAL DISPOSAL COST PER TON	AVG. TRANSPORTATION & DISPOSAL COST/TON	ESTIMATED LANDFILL CAPACITY TONS	TOTAL SITE TRANSPORTATION AND DISPOSAL COST*
1.	REEDBIRD INCINERATOR	2399	400	31.54	$4.57	$5.79	10,000.	$13,249.
2.	BOWLEY'S LANE LANDFILL	708	118	9.31	3.84	4.47	10,000.	3,170.
3.	PULASKI INCINERATOR	4501	750	59.15	4.82	6.09	10,000.	27,439.
	TOTALS	7608	1268	100.00		5 76	30,000.	$43,859.

REMARKS: This is a run simulating existing costs of transportation and disposal at the three disposal sites being used in Baltimore City in 1971. Its purpose is a means of comparison with RUN No. 12, which is a combination of the existing Pulaski Incinerator plus 3 landfill sites. These costs cannot be verified cause Baltimore City's cost accounting does not summerize and itemize these costs.

The landfill operation costs were calculated from the cost curve of Figure 1. The Reedbird and Pulaski Incinerators generally take all the refuse generated except under peak load conditions the overflow from the Pulaski Incinerator is sent unburned to Bowley's Lane. Bowley's Lane Landfill also takes the burned residue from the Pulaski Incinerator. The residue from the Reedbird Incinerator is deposited on a landfill adjacent to the plant both of which are situated on the shore of the Patapsco River.

*Total site transportation and disposal cost includes the cost of land and equipment, but no interest on capital, and no on site collection costs.

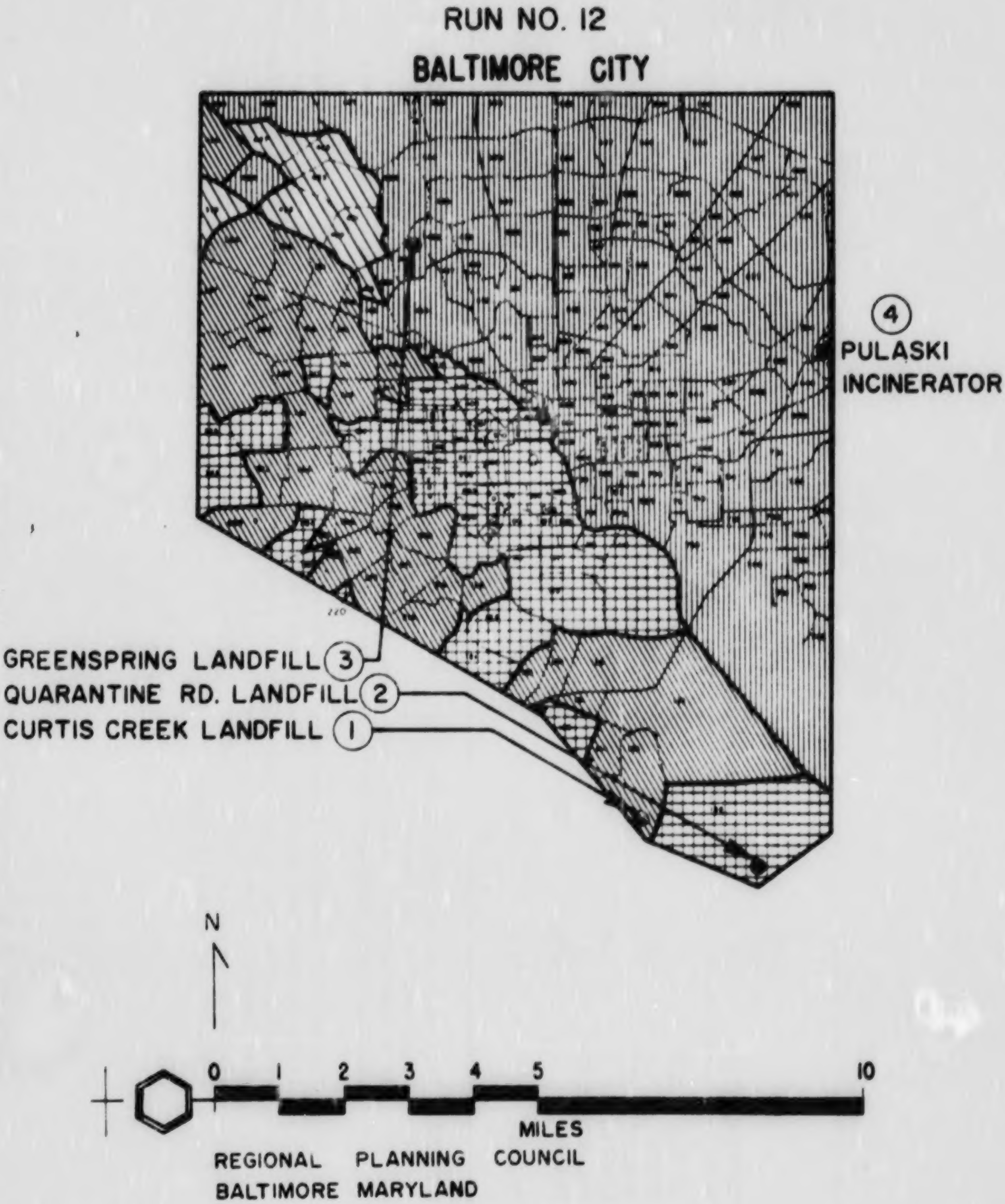
RUN NO. 12
BALTIMORE CITY
④ PULASKI INCINERATOR
GREENSPRING LANDFILL ③
QUARANTINE RD. LANDFILL ②
CURTIS CREEK LANDFILL ①
N
0
1
2
3
4
5
10
MILES
REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND

FIGURE 22

TABLE 14

RUN NO. 12
BALTIMORE CITY ONLY

	DISPOSAL SITES	INPUT TONS PER WK.	INPUT TONS PER DAY	% OF TOTAL GENERATED	LANDFILL OPERATION $ PER TON	LAND + SITE DEV. COST $ PER TON	TOTAL DISPOSAL COST PER TON	AVG. TRANSPORTATION & DISPOSAL COST/TON	ESTIMATED LANDFILL CAPACITY IN TONS	TOTAL SITE TRANSPORTATION & DISPOSAL COST
1.	CURTIS CREEK LANDFILL	1559	260	20.5	1.17	1.50	2.67	4.64	1,000,000	$7,235.
2.	QUARANTINE ROAD LANDFILL	1247	208	16.40	1.32	.94	2.26	4.86	800,000	6,664.
3.	GREENSPRING LANDFILL	372	62	4.90	2.40	2.50	4.90	5.81	240,000	2,164.
4.	PULASKI INCINERATOR	4430	738	58.20	-	-	4.82	6.59	3,740,000	29,217.
	TOTALS	7608	1268	100.00				5.87	5,780,000	$44,679.

REMARKS: The landfill locations used in this run were suggested by the technical advisory staff of the Baltimore City Bureau of Public Works. Site No. 3, the Green Spring Landfill, is now in use. It is used to deposit street sweepings and bulky disposal items that cannot be burned in the incinerators.

Sites No. 1 and 2 are suggested new locations not yet accepted by the City Council. They are rather close together not by choice, but because these are the only available sites that would stand any chance for approval.

The model tells us that the transportation and disposal costs of the site combination of Run 12 is only $820 per week more expensive than the sites now in use (See Run No. 11). The increased costs caused by the unfavorable location of sites 1 and 2 is off set by the lower cost of operation of the landfills compared with incineration. The cost of incineration is based on that now existing. If the present day construction cost of incinerators were considered, the proposed landfills would show a greater cost advantage.

*Total site transportation and disposal cost includes the cost of land and equipment but no interest on capital, and no on route collection costs.

TABLE 15

THE BALTIMORE REGION
REFUSE DISPOSAL SITE SYSTEM DATA

RUN NO. 13

MATRIX COL NO.	TRANS ZONE	AVG.WEEKLY DISPOSAL (TONS)	INPUT TONS PER DAY	REGIONAL TOTAL PERCENT	LANDFILL OPERATION $ PER TON	LAND + SITE COST $ PER TON	TOTAL DISPOSAL $ PER TON	SITE LIFE YEARS	LAND VAL & PER ACRE	REMAINING CAPACITY (TONS)
1	143	2222	370	12.50	1.08	1.00	2.08	13.8	10000.	1600000.
2	230	2222	370	12.50	1.08	1.00	2.08	13.8	10000.	1600000.
3	385	2222	370	12.50	1.08	.10	1.18	13.8	1000.	1600000.
4	390	2222	370	12.50	1.08	.20	1.28	13.8	2000.	1600000.
5	566	2222	370	12.50	1.08	1.00	2.08	13.8	10000.	1600000.
6	766	2222	370	12.50	1.08	1.00	2.08	13.8	10000.	1600000.
7	830	2222	370	12.50	1.08	.10	1.18	13.8	1000.	1600000.
8	951	2227	371	12.50	1.08	.15	1.23	13.8	1500.	1600000.
TOTALS		17781	2963							
RUN NO. 14										
1	143	1113	185	6.26	1.41	1.00	2.41	27.6	10000.	1600000.
2	230	2999	500	16.87	1.85	1.00	2.05	10.3	10000.	1600000.
3	385	7583	1264	14.53	1.08	.10	1.18	11.9	1000.	1600000.
4	390	2999	500	16.87	1.05	.20	1.25	10.3	2000.	1600000.
5	566	2999	500	16.87	1.05	1.00	2.05	10.3	10000.	1600000.
6	766	2999	500	16.87	1.05	1.00	2.05	10.3	10000.	1600000.
7	830	1253	208	7.05	1.32	.10	1.42	24.5	1000.	1600000.
8	951	836	140	4.67	1.68	.15	1.82	36.8	1500.	1600000.
TOTALS		17781	3797	(Surplused Total)						
RUN NO. 15										
1	143	705	117	3.97	1.85	1.00	2.85	43.6	10000.	1600000.
2	230	2999	500	16.87	1.05	1.00	2.05	10.3	10000.	1600000.
3	385	2889	483	16.25	1.07	.10	1.17	10.7	1000.	1600000.
4	390	2999	500	16.87	1.05	.20	1.25	10.3	2000.	1600000.
5	566	2999	500	16.87	1.05	1.00	2.05	10.3	10000.	1600000.
6	766	2999	500	16.87	1.05	1.00	2.05	10.3	10000.	1600000.
7	830	1427	238	8.03	1.22	.10	1.32	21.6	1000.	1600000.
8	951	764	127	4.26	1.77	.15	1.92	40.3	1500.	1600000.

TABLE 16

COST OF OFF ROUTE TRANSPORTATION AND DISPOSAL OF REFUSE BASED ON A SIX DAY WEEK TIME INTERVAL

		RUN NO. 13			RUN NO. 14			RUN NO. 15		
	LANDFILL DISPOSAL SITE	SITE INPUT TONS	COST PER TON	TOTAL SITE COST	SITE INPUT TONS	COST PER TON	TOTAL SITE COST	SITE INPUT TONS	COST PER TON	TOTAL SITE COST*
1.	SMUCKS	1114	$3.39	$3987.	706	$3.47	$2453.	705	$3.90	$2753
2.	RELIABLE	3000	3.84	11536.	3000	3.73	11197.	2999	3.73	11192
3.	HERNWOOD	2583	4.09	10587.	2890	4.16	12023.	2889	4.14	11977
4.	NEW CUT	3000	3.29	9894.	3000	3.27	9822.	2999	3.27	9817
5.	TEXAS	3000	4.47	13417.	3000	4.51	13541.	2999	4.50	13513
6.	NORRIS LANE	3000	3.59	10798.	3000	3.56	10703.	2999	3.56	10705
7.	ANNAPOLIS	1253	3.18	3991.	1427	3.56	5086.	1427	3.47	4954
8.	SWAN CREEK	831	4.74	3939.	758	5.11	3874.	764	5.21	3987
	TOTALS	17781	3.82	67947.	17781	3.86	68699.	17781.	3.87	68900

REMARKS: Runs 14 and 15 are reruns of the same problem as Run No. 13. At the end of each run the percentages of total refuse generated were changed to comply with the redistributed tonnage brought about by surplusing the landfill refuse demand input to the TRANUV program.

---

*Total site cost includes the cost of land and equipment, but no interest on capital, and no on route collection cost.

RUN NO.15 THE BALTIMORE REGION

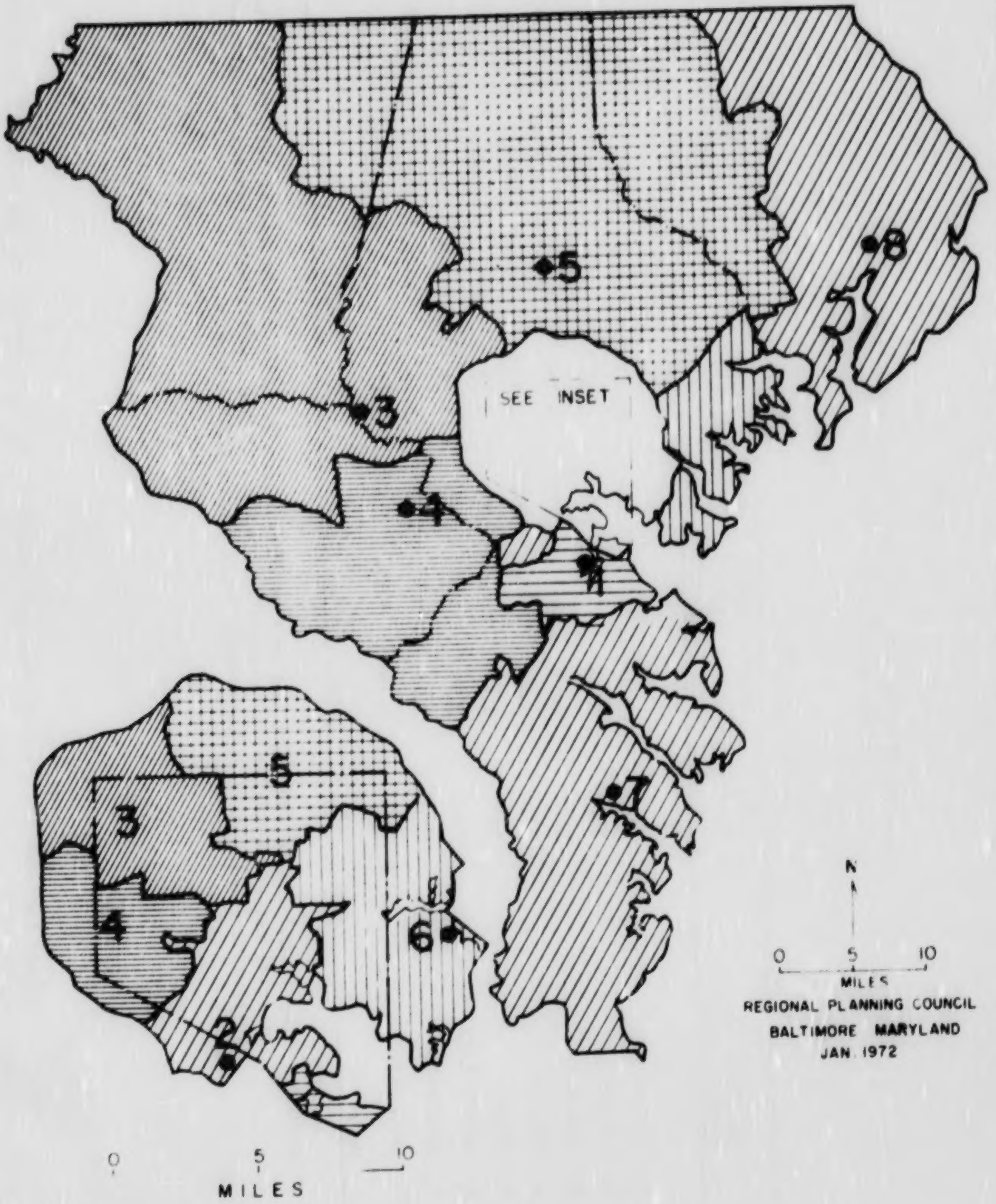
8
5
SEE INSET
3
4
1
7
5
3
4
6
2
N
0 5 10
MILES
REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND
JAN. 1972
0 5 10
MILES

FIGURE 23

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APPENDIX A

UNIVAC 1108 EXEC 8 CONTROL STATEMENTS USED IN THE "TRIPUT" PROGRAM

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UNIVAC 1108 EXEC 8 CONTROL STATEMENTS USED IN THE "TRIPUT" PROGRAM

The following is a description of the control statements used to process the TRIPUT program on the UNIVAC 1108. The symbol ¢ stands for a blank space.

1. $^{7}_{8}$RUN,B/TPC¢TRIPUT,900-72-127,TRASH,3,100

This is the first card of a UNIVAC EXEC 8 Control Statement System. A multiple $^{7}_{8}$ punch is put in column 1 of this statement, as is done in all control cards (except the IN statement following the MAP statement). The printer and the teletype symbol for the $^{7}_{8}$ punch is @, but on the IBM 026 card punch the @ symbol makes a $^{4}_{8}$ punch. So on this machine the $^{7}_{8}$ punch must be made by punching 7 and 8 while multiple punch key is held down. If the $^{7}_{8}$ punch is not done properly the UNIVAC will abort the run.

The B indicates the priority of the job. An A in this position would be a higher priority and a C a lower one. Priorities are assigned by the computer center.

The TPC separated from the B by / indicates the restrictions placed upon the run by the programmer. T for the time limit, P for page limit on the printer, and C for card limit on the punch. This prevents any possible berserk movements caused by program errors or unforeseen conditions. The numerical limits follow the word TRASH and in this case means the central processor time is limited to 3 minutes, the number of printed pages is limited to 100 and no limit has been placed on the cards punched, because the program does not punch cards. The TPC is not necessary when using the teletype.

Following the TPC and a blank is the source program name, TRIPUT, followed by the assigned accounting number 900-72-127,. This is followed by the project name, (TRASH) invented by the programmer. Deviation from this format will cause a computer stop.

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2. $^{7}_{8}$ASG,CP¢DISPOSE,F/1/TRK/400

The $^{7}_{8}$ASG, indicates this control statement is an assignment of an input-output device. This must be done for tapes, magnetic drums or other storage devices.

If there were an A following the $^{7}_{8}$ASG, it would indicate that the file had been previously assigned, otherwise, if the program is being run initially, CP is punched. The C means to catalogue in the FASTRAND (magnetic file), if the program runs normally. P stands for a public file rather than a private one. If the program does not go thru to the $^{7}_{8}$ FIN card, it will not be catalogued, and any attempt to call it from the FASTRAND file will cause a NOT IN FILE diagnostic, and the run will be aborted. Following the A or CP option is a blank (¢) followed by the file name DISPOSE,. The F/1/TRK/400 indicates that a FASTRAND file will be assigned to the DISPOSE file with 400 tracks of space. One track is equal to 1792 words. In this model the DISPOSE file will contain the TRIPUT FORTRAN Symbolic (source) program, the TRIPUT relocatable program, the MAPTRI assembled symbolic program, the TRIPUT absolute (machine language) program, and the card input data DISDATA. Use of the $^{7}_{8}$PRT,T¢DISPOSE command will list a table of contents of the file on the printer.

3. $^{7}_{8}$DELETE,C¢TDUMP.

This command causes the TDUMP file that is catalogued on a previous TRIPUT run to be deleted. The C option causes a normal run exit after an error condition. Immediately following this command, the $^{7}_{8}$ASG command will cause the TDUMP file to be reassigned, so as to be ready to receive new output from TRIPUT. The DELETE command is used in order to avoid an aborted run in case the TDUMP file has been obliterated by the service center without notice, and the $^{7}_{8}$ASG command is mistakenly used with an A option.

4. $^{7}_{8}$ASG,CP¢TDUMP.F/1/TRK/256

This control statement assigns to the TDUMP file 256 tracks in the FASTRAND file. The CP means catalogue public. One track is equal to 1792 words.

5. $^{7}_{8}$ASG,T¢10.

This control statement assigns the internal FORTRAN file number 10 to a temporary file. At the compilation of the program the contents of this file will be transferred to TDUMP a cataloged permanent file.

6. $^{7}_{8}$ASG,TM¢SKIM65,8C,2767

This assigns to a temporary file, the input SKIM Tree tape called SKIM65 and numbered 2767. The tape and its number is furnished by the U of M Computer Service Bureau. T stands for temporary and M for medium density tape. The 8C means Uniservo VIIIC 7 track tape.

7. $^{7}_{8}$USE¢8,SKIM65

This statement causes the internal FORTRAN program input read statement 8 to be equivalent to the SKIM65 temporary file containing the Skim Tree data.

8. $^{7}_{8}$FOR,IS¢DISPOSE.TRIPUT,.TRIPUT

This statement tells the UNIVAC 1108 EXEC 8 system to compile the TRIPUT symbolic (source) program and put it into the DISPOSE file. It means this is the initial compilation. If the DISPOSE file contains a previous compilation, the option would be U for update. S is for symbolic or source program. The sequence of the letters in the option is unimportant. It may be IS or SI. The FORTRAN source deck is placed after the $^{7}_{8}$FOR card. Thereupon the source deck is compiled and a source listing made on the printer. If a source listing is not wanted the FORTRAN compile statement is written: $^{7}_{8}$FOR.ISN¢DISPOSE.TRIPUT,.TRIPUT. The N option means no list. The compilation from the source deck is called the relocatable program.

9. $^{7}_{8}$MAP,I¢DISPOSE.MAPTRI,DISPOSE.TRIPUT

This control statement assembles the relocatable program TRIPUT and converts it to an obsolute program (machine language) and stores it in the file DISPOSE. A future use of the program may be had by executing TRIPUT without having the source program reassembled. The I following $^{7}_{8}$MAP, is for initial assembly of the absolute program. If it is not the first MAP program assembly, then there is in the DISPOSE file a previous assembled absolute program. In this case U for update would be used instead of I. Following the I and before DISPOSE in the statement a blank is necessary. Absence of the blank will cause the EXEC 8 to abort the run.

10. IN DISPOSE.TRIPUT

This control statement is without a ${}^{7}_{8}$ multiple punch in column 1. It allows assembly of all elements from any number of files, specifically that named after the IN statement. The MAP (card 9) and IN statements are followed by the printing of a table showing the starting address and the address limits and a word count of storage space indicated by IBANK and DBANK. The addition of these two numbers is the measure of total storage used. The TRIPUT program uses 11,433 words of storage.

11. ${}^{7}_{8}$ELT.IL¢DISPOSE.DISDATA

This control command causes the following card data to be read into the so-called control stream and then put into the DISPOSE file. Or, if U is used instead of I, the file will be updated. This means that if the card deck has been previously (initially) read, the data cards read in the current run will be put in the DISPOSE file following the old data. The computer will, however, process the latest data in file. Each time the program is run, a new set of data will be put in file behind the old data; and it will stay there until the file is DELETED. The option letter L indicates that a printed listing of the card data is desired. If there are no data changes on the next run, the data may be read from file without having to reread the cards.

12. ${}^{7}_{8}$XQT¢DISPOSE.TRIPUT

This is the execution statement. It follows the data cards in the deck, if there are any. It says execute TRIPUT program stored in the DISPOSE file. After this card the TRIPUT program is run, then, if all is in order the printer indicates normal execution and prints the amount of CP (central processor) time.

13. ${}^{7}_{8}$ADD,P¢DISPOSE.DISDATA

This control card causes the DISDATA element of the DISPOSE file to be inserted into the computer run stream. The option P after ${}^{7}_{8}$ADD, tells the computer to print the command.

14. ${}^{7}_{8}$ELT,I¢TDUMP.ONE

After the TRIPUT program has calculated the program matrix size, tons of supply and demand, and the costs of transportation and disposal from all zones, and stored them in the temporary file 10, the ${}^{7}_{8}$ELT,I¢TDUMP.ONE command puts the data into the permanent file TDUMP. The I means that this is the initial time that this has been done and not an updating. If a listing of the data is wanted, the control statement would be ${}^{7}_{8}$ELT,L¢TDUMP.ONE. In this case because the printout would be 240 pages the L was omitted, furthermore there seems to be no need for a printout. ONE is the element name invented for the storage area in the TDUMP file.

15. ${}^{7}_{8}$ADD,P¢10.

This control statement tells the computer to insert the block of card images stored in temporary file 10 into the run stream of the computer. The option P means print this command on the printer. Later, when the listing is examined, the evidence will be there to indicate that this command was not forgotten.

16. ${}^{7}_{8}$END

This statement is required after the ${}^{7}_{8}$ELT statement to separate the current run from the data being put into file.

17. ${}^{7}_{8}$PRT,F¢TDUMP

TDUMP is a separate file and not a part of DISPOSE file. This control card requests a record of the last cataloguing of the output from the TRIPUT program. This is a check on whether the data has been put into the TDUMP file and when. F means list the directory item for a catalogued file.

18. $\overset{7}{8}$PRT,T¢TDUMP.

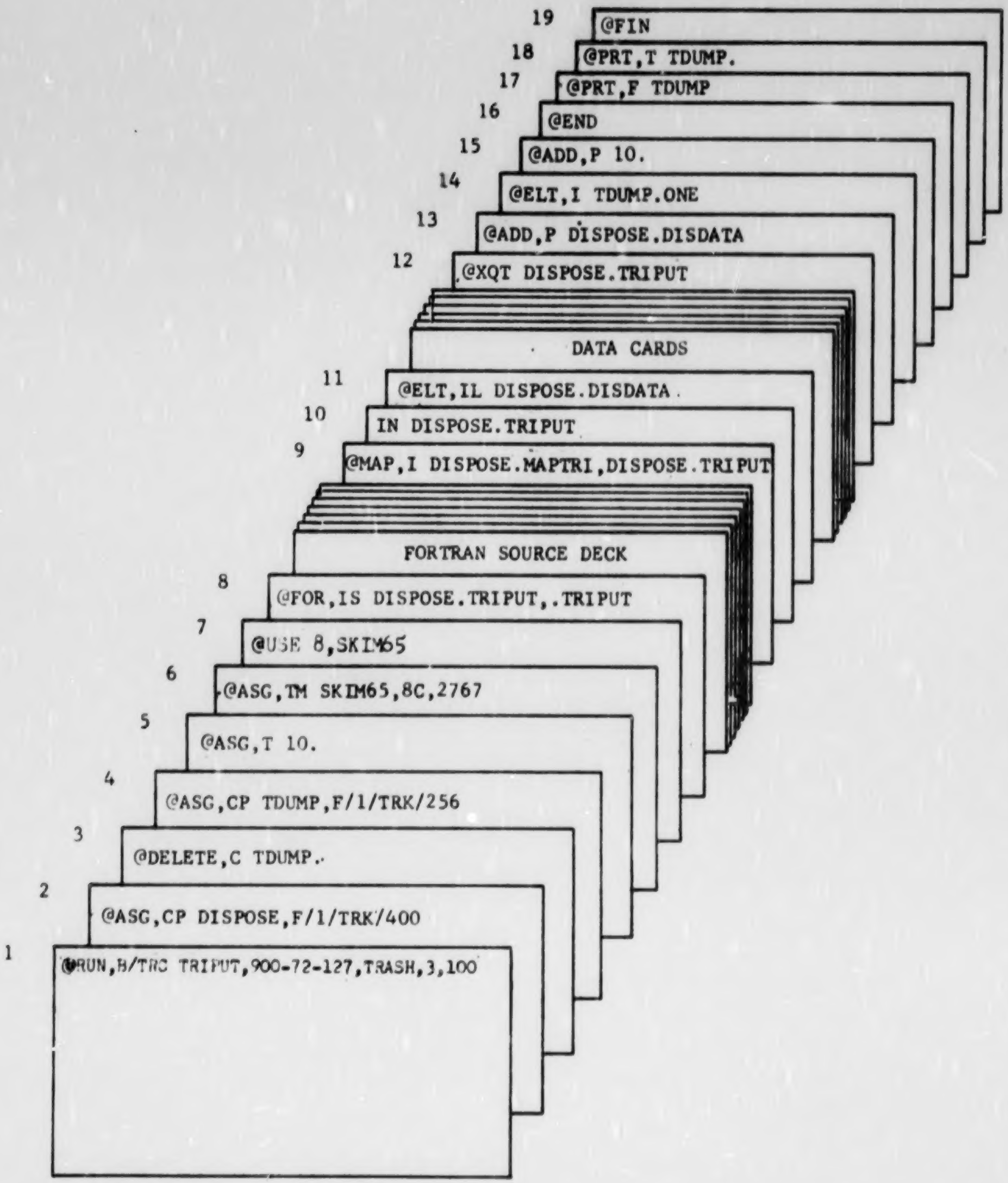
This control statement is used to cause a record of the creation of the data in the TDUMP file to be printed. The option T causes the listing of a table of the contents of the TDUMP file existing in FASTRAND.

19. $\overset{7}{8}$FIN

This is the last control statement of the run. It terminates the run and records the time, accounting number, etc.

Figure 24 on page 135 shows how the control statements are stacked in the program bundle, and Appendix D shows the results caused by the statements when used in the sample problem.

TRIPUT PROGRAM BUNDLE FOR THE UNIVAC 1108 EXEC 8 SYSTEM



```
1  @RUN,B/TRC TRIPUT,900-72-127,TRASH,3,100
2  @ASG,CP DISPOSE,F/1/TRK/400
3  @DELETE,C TDUMP.
4  @ASG,CP TDUMP,F/1/TRK/256
5  @ASG,T 10.
6  @ASG,TM SKIM65,8C,2767
7  @USE 8,SKIM65
8  @FOR,IS DISPOSE.TRIPUT,.TRIPUT
   FORTRAN SOURCE DECK
9  @MAP,I DISPOSE.MAPTRI,DISPOSE.TRIPUT
10 IN DISPOSE.TRIPUT
11 @ELT,IL DISPOSE.DISDATA
   DATA CARDS
12 @XQT DISPOSE.TRIPUT
13 @ADD,P DISPOSE.DISDATA
14 @ELT,I TDUMP.ONE
15 @ADD,P 10.
16 @END
17 @PRT,F TDUMP
18 @PRT,T TDUMP.
19 @FIN
```

FIGURE 24

APPENDIX B

UNIVAC 1108 EXEC 8 CONTROL CARDS USED IN THE "TRANUV" PROGRAM

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UNIVAC 1108 EXEC 8 CONTROL CARDS USED IN THE "TRANUV" PROGRAM

The following is a description of the control statements used to process the TRANUV program on the UNIVAC 1108. The symbol ¢ stands for a blank space.

1. $^{7}_{8}$RUN,B/TPC¢TRANUV,900-72-127,TRASH,10,100

This control statement has been explained when describing the "TRIPUT" program. TRANUV is used in the control statement instead of TRIPUT and the computer time is limited to 10 min. and 100 pages.

2. $^{7}_{8}$ASG,A¢TDUMP

This statement assigns the TDUMP file. The file has been previously assigned in the TRIPUT program using a CP option, therefore the option here is an A.

3. $^{7}_{8}$PRT,T¢TDUMP

This control statement with the T option causes a record of the last catalogue of TDUMP file to be printed. This is a check on the function of the TRIPUT program. This record should be checked against the same statement at the end of the TRIPUT run. This will disclose whether the computer center has failed to put the last TRIPUT data run into the TDUMP file.

4. $^{7}_{8}$ASG,A¢DISPOSE

This statement is an assignment of the DISPOSE file. The A option indicates that it has been assigned on a previous run, otherwise the option would be CP meaning catalogue public. If the wrong assumption is made on this control card concerning the option, the program will abort and print a diagnostic message. That is, if CP is used when the file already exists, or the A is used when a file has not been previously assigned, the EXEC 8 will stop the computer.

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5. ${}^{7}_{8}$FOR,IS¢DISPOSE.TRANUV

This control statement precedes the source deck and it commands the computer to compile the FORTRAN IV Source program. The output goes to the DISPOSE file as a relocatable program after the ${}^{7}_{8}$FIN statement is encountered. The relocatable binary program is assembled into an absolute program later by the MAP statement. If an N is not present in the option, thus, ${}^{7}_{8}$FOR,SIN¢DISPOSE.TRANUV the computer will print a source listing preceded by a table showing the location of all variables in storage. The option I is for the initial compilation, which means at this stage no other previous TRANUV relocatable programs have been compiled and put in the FASTRAND file DISPOSE. Otherwise the option would be U meaning update instead of I. Failure to distinguish these two conditions will cause a program stop. The source deck follows this statement. The TRANUV program has no card data input. Input is from the FASTRAND file.

6. ${}^{7}_{8}$MAP,I¢DISPOSE.TRANMAP,DISPOSE.TRANXQT

This command causes assembly of relocatable elements in the DISPOSE file and identifies the symbolic output element as TRANMAP.

7. IN¢DISPOSE.TRANUV

This specification identifies the absolute element as TRANUV. Tables printed by the ${}^{7}_{8}$MAP statement give locations in storage of segments of the program and a word count of the program. The TRANUV program contains 5,129 plus 36,179 words in storage or 41,308 words total.

8. ${}^{7}_{8}$XQT¢DISPOSE.TRANXQT

This command causes execution of the absolute program TRANXQT assembled by the ${}^{7}_{8}$MAP statement. The program output follows this statement. The period after DISPOSE is part of the statement.

9. ${}^{7}_{8}$FIN

This statement terminates the program run, if there are no stoppages flagged by diagnostics. If stoppages occur before the ${}^{7}_{8}$FIN statement no files will be saved. A request for files in a later run will cause a NOT IN FILE diagnostic on the printer.

UNIVAC 1108 EXEC 8 CONTROL CARDS USED IN THE "TRANUV" PROGRAM

The following is a description of the control statements used to process the TRANUV program on the UNIVAC 1108. The symbol ¢ stands for a blank space.

1. $^{7}_{8}$RUN,B/TPC¢TRANUV,900-72-127,TRASH,10,100

This control statement has been explained when describing the "TRIPUT" program. TRANUV is used in the control statement instead of TRIPUT and the computer time is limited to 10 min. and 100 pages.

2. $^{7}_{8}$ASG,A¢TDUMP

This statement assigns the TDUMP file. The file has been previously assigned in the TRIPUT program using a CP option, therefore the option here is an A.

3. $^{7}_{8}$PRT,T¢TDUMP

This control statement with the T option causes a record of the last catalogue of TDUMP file to be printed. This is a check on the function of the TRIPUT program. This record should be checked against the same statement at the end of the TRIPUT run. This will disclose whether the computer center has failed to put the last TRIPUT data run into the TDUMP file.

4. $^{7}_{8}$ASG,A¢DISPOSE

This statement is an assignment of the DISPOSE file. The A option indicates that it has been assigned on a previous run, otherwise the option would be CP meaning catalogue public. If the wrong assumption is made on this control card concerning the option, the program will abort and print a diagnostic message. That is, if CP is used when the file already exists, or the A is used when a file has not been previously assigned, the EXEC 8 will stop the computer.

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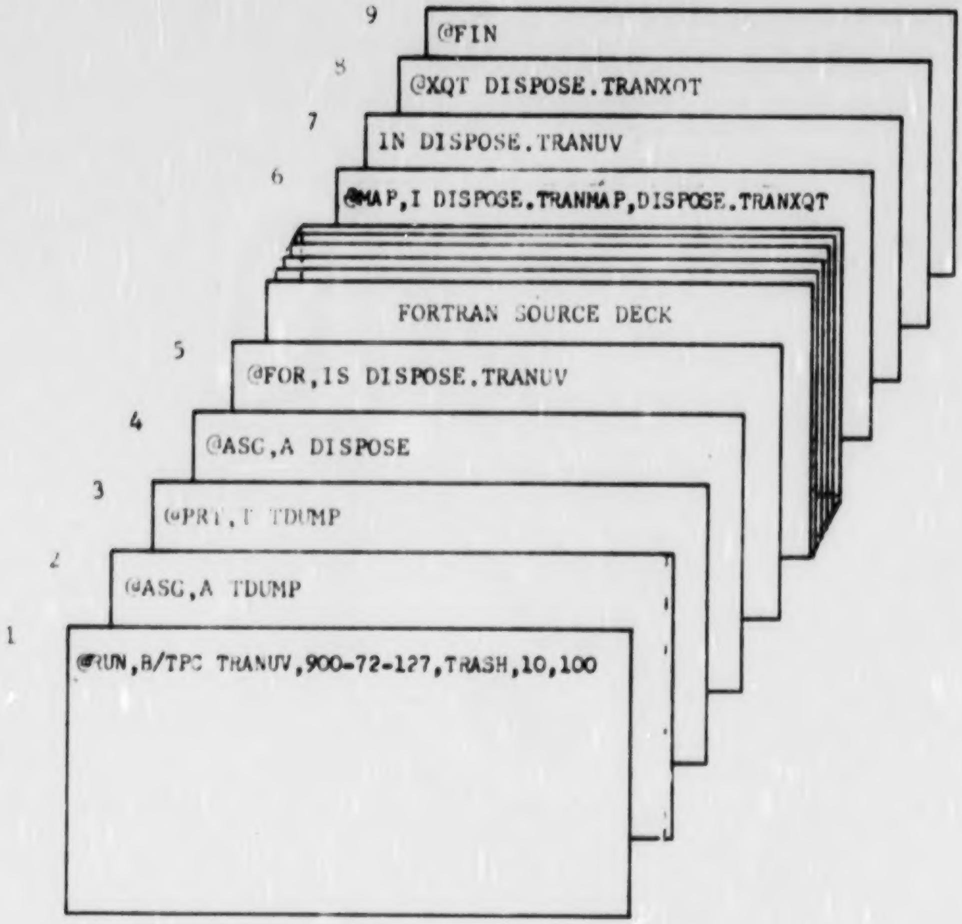
Figure 25 on page 142 shows how the control statements are arranged in the TRANUV program bundle and APPENDIX C shows the results of using these statements in the sample problem.

The TRIPUT and TRANUV programs may be run in tandem in the same batch run on the computer Figure 26 shows the program bundle and the sequence of the EXEC 8 Control Cards to accomplish this result.

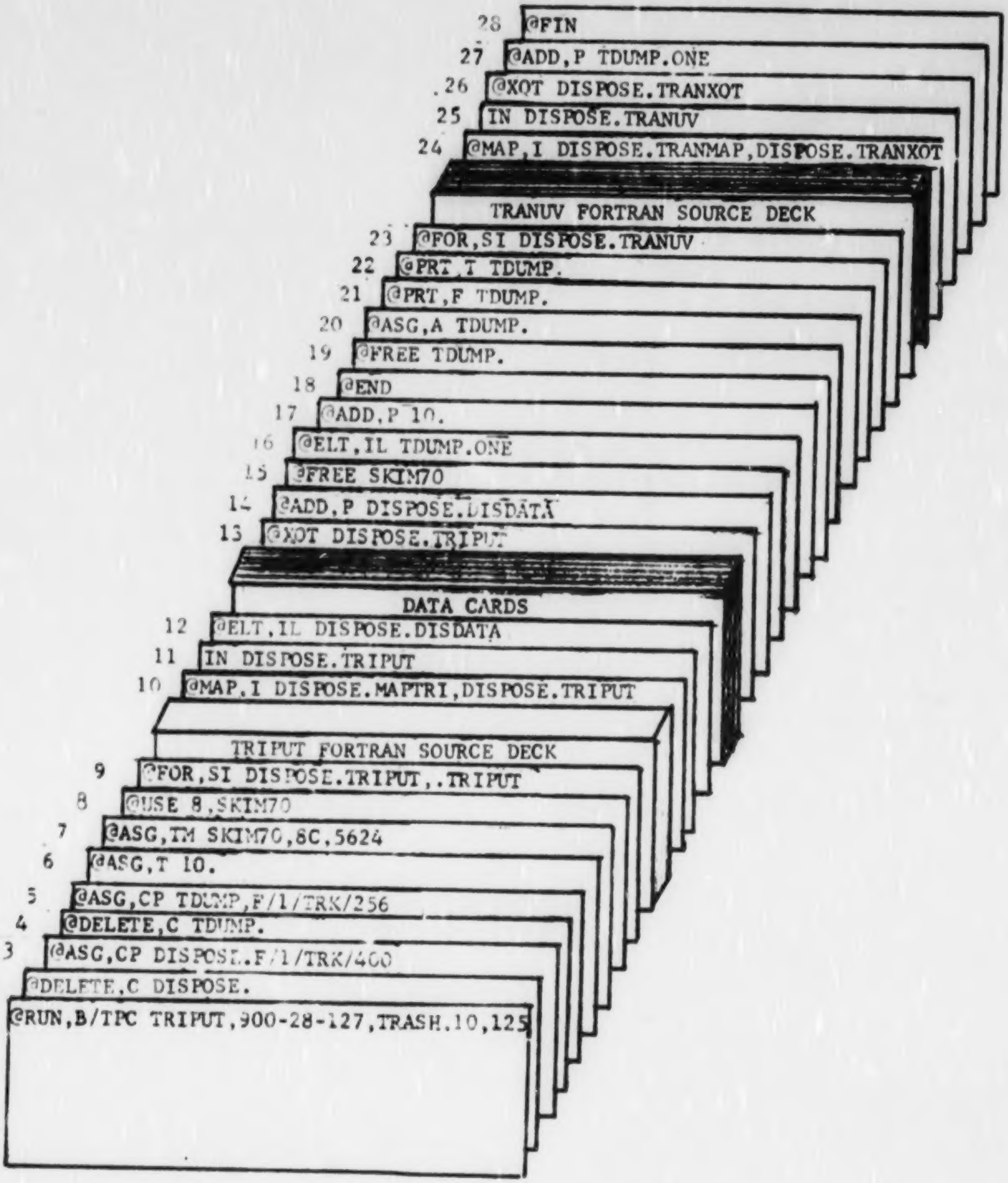
TRANUV PROGRAM BUNDLE FOR THE UNIVAC 1108 EXEC. 8 SYSTEM



```
1  @RUN,B/TPC TRANUV,900-72-127,TRASH,10,100
2  @ASG,A TDUMP
3  @PRT,T TDUMP
4  @ASG,A DISPOSE
5  @FOR,IS DISPOSE.TRANUV
   FORTRAN SOURCE DECK
6  @MAP,I DISPOSE.TRANMAP,DISPOSE.TRANXQT
7  IN DISPOSE.TRANUV
8  @XQT DISPOSE.TRANXQT
9  @FIN
```

FIGURE 25

TRIPUT - TRANUV TANDEM PROGRAM BUNDLE FOR THE UNIVAC 1108 EXEC 8 SYSTEM



```
28 @FIN
27 @ADD,P TDUMP.ONE
26 @XQT DISPOSE.TRANXOT
25 IN DISPOSE.TRANUV
24 @MAP,I DISPOSE.TRANMAP,DISPOSE.TRANXOT
   TRANUV FORTRAN SOURCE DECK
23 @FOR,SI DISPOSE.TRANUV
22 @PRT,T TDUMP.
21 @PRT,F TDUMP.
20 @ASG,A TDUMP.
19 @FREE TDUMP.
18 @END
17 @ADD,P 10.
16 @ELT,IL TDUMP.ONE
15 @FREE SKIM70
14 @ADD,P DISPOSE.DISDATA
13 @XQT DISPOSE.TRIPUT
   DATA CARDS
12 @ELT,IL DISPOSE.DISDATA
11 IN DISPOSE.TRIPUT
10 @MAP,I DISPOSE.MAPTRI,DISPOSE.TRIPUT
   TRIPUT FORTRAN SOURCE DECK
9 @FOR,SI DISPOSE.TRIPUT,.TRIPUT
8 @USE 8,SKIM70
7 @ASG,TM SKIM70,8C,5624
6 @ASG,T 10.
5 @ASG,CP TDUMP,F/1/TRK/256
4 @DELETE,C TDUMP.
3 @ASG,CP DISPOSE.,F/1/TRK/400
2 @DELETE,C DISPOSE.
1 @RUN,B/TPC TRIPUT,900-28-127,TRASH.10,125
```

FIGURE 26

APPENDIX C

PARTIAL CARD IMAGE LISTING OF THE OUTPUT OF THE TRIPUT AND THE INPUT OF THE TRANUV PROGRAM

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PARTIAL CARD IMAGE LISTING OF THE OUTPUT OF "TRIPUT" AND THE INPUT TO "TRANUV" PROGRAMS

```
@ELT.IL TDUMP.ONE
ELT 005-12/13-19:49


@ADD.P ID.
000001         000          550       23
000002         000            1        1
000003         000            2        1
000004         000            3        1
000005         000            4        1
000006         000            5        2
000007         000            6        2
000008         000            7        3
000009         000            8        3
000010         000            9        1
000011         000           10        2
000012         000           11       10
000013         000           12       16
000014         000           13        8
000015         000           14       13
000016         000           15        4
000017         000           16        2
000018         000           17       26
000019         000           18       28
000020         000           19        3
000021         000           20       23
000022         000           21       12
000023         000           22       48
000024         000           23        4
000025         000           24        1
000026         000           25       22
000027         000           26       24
000028         000           27       60
000029         000           28       66
000030         000           29        5
000031         000           30        3
000032         000           31        3
000033         000           32       20
000034         000           33       11
000035         000           34       66
000036         000           35       38
000037         000           36       18
000038         000           37       73
000039         000           38       64
000040         000           39       58
000041         000           40       62
000042         000           41       51
000043         000           42       64
000044         000           43       40
000045         000           44       57
000046         000           45       50
000047         000           46       14
000048         000           47       32
000049         000           48       31
000050         000           49       69
000051         000           50       33
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000052         000           51       53
000053         000           52       46
000054         000           53       52
000055         000           54       36
000056         000           55       43
000057         000           56       13
000058         000           57       29
000059         000           58       23
000060         000           59       68
000061         000           60       63
000062         000           61        5
000063         000           62       88
000064         000           63       21
000065         000           64        4
000066         000           65       40
000067         000           66       40
000068         000           67       33
000069         000           68       16
000070         000           69       24
000071         000           70       30
000072         000           71       41
000073         000           72       29
000074         000           73       40
000075         000           74       11
000076         000           75       18
000077         000           76       27
000078         000           77        7
000079         000           78       30
000080         000           79       36
000081         000           80        3
000082         000           81       30
000083         000           82       22
000084         000           83        2
000085         000           84       11
000086         000           85      109
000087         000           86        1
000088         000           87       42
000089         000           88       25
000090         000           89       59
000091         000           90       14
000092         000           91        6
000093         000           92       29
000094         000           93       57
000095         000           94       11
000096         000           95       30
000097         000           96       49
000098         000           97       67
000099         000           98       34
000100         000           99       41
000101         000          100       50
000102         000          101       16
000103         000          102       13
000104         000          103       69
000105         000          104       25
000106         000          105       28
000107         000          106        8
000108         000          107       16
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PARTIAL CARD IMAGE LISTING OF THE OUTPUT OF "TRIPUT"
AND THE INPUT TO "TRANUV" PROGRAMS
(Continued)

```
000109        000        108        8
000110        000        109       16
000111        000        110       11
000112        000        111       13
000113        000        112       13
000114        000        113       19
000115        000        114       18
000116        000        115       26
000117        000        116       10
000118        000        117       10
000119        000        118       39
000120        000        119       17
000121        000        120        9
000122        000        121       23
000123        000        122       77
000124        000        123       66
000125        000        124       13
000126        000        125       56
000127        000        126       21
000128        000        127       32
000129        000        128       43
000130        000        129       39
000131        000        130       53
000132        000        131       44
000133        000        132       24
000134        000        133       39
000135        000        134       27
000136        000        135       63
000137        000        136       35
000138        000        137       34
000139        000        138       64
000140        000        139       43
000141        000        140       57
000142        000        141       41
000143        000        142       48
000144        000        143       56
000145        000        144       23
000146        000        145       18
000147        000        146       41
000148        000        147       17
000149        000        148       70
000150        000        149       86
000151        000        150       34
000152        000        151       24
000153        000        152       23
000154        000        153       44
000155        000        154       19
000156        000        155       43
000157        000        156       66
000158        000        157       21
000159        000        158       69
000160        000        159       12
000161        000        160       20
000162        000        161       36
000163        000        162       52
000164        000        163       13
000165        000        164       32
```

```
000166        000        165       43
000167        000        166       64
000168        000        167       47
000169        000        168       13
000170        000        169       11
000171        000        170       67
000172        000        171       31
000173        000        172       35
000174        000        173       16
000175        000        174       25
000176        000        175       51
000177        000        176        9
000178        000        177       14
000179        000        178       22
000180        000        179       22
000181        000        180       19
000182        000        181        1
000183        000        182        9
000184        000        183       25
000185        000        184       37
000186        000        185       19
000187        000        186       25
000188        000        187       40
000189        000        188       42
000190        000        189       34
000191        000        190       54
000192        000        191        9
000193        000        192       24
000194        000        193       36
000195        000        194        6
000196        000        195        6
000197        000        196       16
000198        000        197        9
000199        000        198       16
000200        000        199        7
000201        000        200       22
000202        000        201       32
000203        000        202       30
000204        000        203       22
000205        000        204        9
000206        000        205       13
000207        000        206       22
000208        000        207       11
000209        000        208        8
000210        000        209        5
000211        000        210        7
000212        000        211       27
000213        000        212       13
000214        000        213       20
000215        000        214       49
000216        000        215       40
000217        000        216       87
000218        000        217       60
000219        000        218       60
000220        000        219       50
000221        000        220       40
000222        000        221       46
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PARTIAL CARD IMAGE LISTING OF THE OUTPUT OF "TRIPUT" AND THE INPUT TO "TRANUV" PROGRAMS
(Continued)

```
000223     000      222     7     000280     000      279    40
000224     000      223    29     000281     000      280    27
000225     000      224     7     000282     000      281    39
000226     000      225     7     000283     000      282    45
000227     000      226    26     000284     000      283    63
000228     000      227    28     000285     000      284    59
000229     000      228    50     000286     000      285    44
000230     000      229    30     000287     000      286    36
000231     000      230    41     000288     000      287    41
000232     000      231    67     000289     000      288    66
000233     000      232   108     000290     000      289     3
000234     000      233    63     000291     000      290    27
000235     000      234    50     000292     000      291     2
000236     000      235    27     000293     000      292    43
000237     000      236    39     000294     000      293    13
000238     000      237    33     000295     000      294    21
000239     000      238    22     000296     000      295    50
000240     000      239    30     000297     000      296    34
000241     000      240    30     000298     000      297    38
000242     000      241    11     000299     000      298    63
000243     000      242    23     000300     000      299    73
000244     000      243    31     000301     000      300    23
000245     000      244     9     000302     000      301    23
000246     000      245    22     000303     000      302    12
000247     000      246    21     000304     000      303    17
000248     000      247    42     000305     000      304    65
000249     000      248     7     000306     000      305    33
000250     000      249    17     000307     000      306    60
000251     000      250    19     000308     000      307    78
000252     000      251    36     000309     000      308    35
000253     000      252    52     000310     000      309    63
000254     000      253    25     000311     000      310     9
000255     000      254     9     000312     000      311    51
000256     000      255     8     000313     000      312    56
000257     000      256     8     000314     000      313     9
000258     000      257    37     000315     000      314    58
000259     000      258    66     000316     000      315    36
000260     000      259    27     000317     000      316    19
000261     000      260    57     000318     000      317    29
000262     000      261    29     000319     000      318    45
000263     000      262     9     000320     000      319    41
000264     000      263    49     000321     000      320    10
000265     000      264    33     000322     000      321    33
000266     000      265    29     000323     000      322    54
000267     000      266    53     000324     000      323    37
000268     000      267    14     000325     000      324     9
000269     000      268    11     000326     000      325    38
000270     000      269    19     000327     000      326    32
000271     000      270     9     000328     000      327     3
000272     000      271    40     000329     000      328    44
000273     000      272     8     000330     000      329    35
000274     000      273    66     000331     000      330    27
000275     000      274    10     000332     000      331    71
000276     000      275    54     000333     000      332    45
000277     000      276    34     000334     000      333    39
000278     000      277    47     000335     000      334    25
000279     000      278    66     000336     000      335    47
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PARTIAL CARD IMAGE LISTING OF THE OUTPUT OF "TRIPUT" AND THE INPUT TO "TRANUV" PROGRAMS
(Continued)

```
000337      000      336    28    000394      000      393   1
000338      000      337    33    000395      000      394   4
000339      000      338    19    000396      000      395   3
000340      000      339    12    000397      000      396   3
000341      000      340    19    000398      000      397
000342      000      341    22    000399      000      398   1
000343      000      342    29    000400      000      399   8
000344      000      343     7    000401      000      400   1
000345      000      344    25    000402      000      401   3
000346      000      345    34    000403      000      402   4
000347      000      346    18    000404      000      403
000348      000      347    26    000405      000      404   2
000349      000      348    29    000406      000      405   7
000350      000      349    39    000407      000      406   5
000351      000      350    33    000408      000      407   2
000352      000      351    34    000409      000      408   4
000353      000      352    47    000410      000      409   1
000354      000      353    39    000411      000      410   1
000355      000      354    53    000412      000      411
000356      000      355    89    000413      000      412   2
000357      000      356    27    000414      000      413
000358      000      357    31    000415      000      414   2
000359      000      358    50    000416      000      415
000360      000      359    23    000417      000      416
000361      000      360    27    000418      000      417   1
000362      000      361     3    000419      000      418
000363      000      362    24    000420      000      419   2
000364      000      363    32    000421      000      420
000365      000      364    19    000422      000      421   5
000366      000      365    10    000423      000      422   1
000367      000      366    42    000424      000      423   5
000368      000      367    11    000425      000      424
000369      000      368    62    000426      000      425   5
000370      000      369    41    000427      000      426   3
000371      000      370    21    000428      000      427   4
000372      000      371    26    000429      000      428   4
000373      000      372    52    000430      000      429   5
000374      000      373   147    000431      000      430   4
000375      000      374    55    000432      000      431   1
000376      000      375     5    000433      000      432
000377      000      376    51    000434      000      433   4
000378      000      377    24    000435      000      434
000379      000      378    13    000436      000      435
000380      000      379    81    000437      000      436
000381      000      380     7    000438      000      437
000382      000      381    23    000439      000      438
000383      000      382    29    000440      000      439   2
000384      000      383    26    000441      000      440   1
000385      000      384    20    000442      000      441   3
000386      000      385    12    000443      000      442   1
000387      000      386    41    000444      000      443   2
000388      000      387     3    000445      000      444   4
000389      000      388     2    000446      000      445   3
000390      000      389    16    000447      000      446   6
000391      000      390    54    000448      000      447   2
000392      000      391    10    000449      000      448   4
000393      000      392    34    000450      000      449   4
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PARTIAL CARD IMAGE LISTING OF THE OUTPUT OF "TRIPUT" AND THE INPUT TO "TRANUV" PROGRAMS
(Continued)

```
000451     000     450    70     000508     000     507    16
000452     000     451    43     000509     000     508    40
000453     000     452    50     000510     000     509    16
000454     000     453    30     000511     000     510    82
000455     000     454    31     000512     000     511    38
000456     000     455     4     000513     000     512    27
000457     000     456     3     000514     000     513    23
000458     000     457    71     000515     000     514    35
000459     000     458    59     000516     000     515    15
000460     000     459    15     000517     000     516    17
000461     000     460     3     000518     000     517    38
000462     000     461    53     000519     000     518    24
000463     000     462    22     000520     000     519    25
000464     000     463    29     000521     000     520    55
000465     000     464    43     000522     000     521    14
000466     000     465    20     000523     000     522    10
000467     000     466    56     000524     000     523    53
000468     000     467   111     000525     000     524    42
000469     000     468    25     000526     000     525    40
000470     000     469     6     000527     000     526    20
000471     000     470    30     000528     000     527    12
000472     000     471    14     000529     000     528    15
000473     000     472    18     000530     000     529    26
000474     000     473    70     000531     000     530    18
000475     000     474    31     000532     000     531    14
000476     000     475    88     000533     000     532    32
000477     000     476    12     000534     000     533    38
000478     000     477    12     000535     000     534    38
000479     000     478    14     000536     000     535    17
000480     000     479    21     000537     000     536    38
000481     000     480   139     000538     000     537    42
000482     000     481    92     000539     000     538    35
000483     000     482    17     000540     000     539    35
000484     000     483    46     000541     000     540    13
000485     000     484    54     000542     000     541    34
000486     000     485    50     000543     000     542    43
000487     000     486    39     000544     000     543   163
000488     000     487    10     000545     000     544   215
000489     000     488   113     000546     000     545    29
000490     000     489    33     000547     000     546    15
000491     000     490    26     000548     000     547    14
000492     000     491    33     000549     000     548   106
000493     000     492    92     000550     000     549    26
000494     000     493    33     000551     000     550    11
000495     000     494    29     000552     000       1  3040
000496     000     495    15     000553     000       2  2112
000497     000     496    29     000554     000       3   154
000498     000     497    29     000555     000       4    51
000499     000     498    27     000556     000       5  2489
000500     000     499    20     000557     000       6   977
000501     000     500    15     000558     000       7   622
000502     000     501    28     000559     000       8  1955
000503     000     502    10     000560     000       9  4569
000504     000     503    14     000561     000      10    90
000505     000     504   142     000562     000      11    78
000506     000     505    22     000563     000      12    90
000507     000     506    10     000564     000      13    65
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PARTIAL CARD IMAGE LISTING OF THE OUTPUT OF "TRIPUT" AND THE INPUT TO "TRANUV" PROGRAMS
(Continued)

```
000565        000         14     192
000566        000         15      53
000567        000         16     186
000568        000         17     115
000569        000         18      28
000570        000         19      83
000571        000         20      56
000572        000         21     149
000573        000         22     236
000574        000         23     393
000575        000          1       1      909
000576        000          2       1      905
000577        000          3       1      910
000578        000          4       1      909
000579        000          5       1      762
000580        000          6       1      766
000581        000          7       1      725
000582        000          8       1      725
000583        000          9       1      914
000584        000         10       1      778
000585        000         11       1      642
000586        000         12       1      611
000587        000         13       1      621
000588        000         14       1      613
000589        000         15       1      655
000590        000         16       1      722
000591        000         17       1      592
000592        000         18       1      585
000593        000         19       1      692
000594        000         20       1      593
000595        000         21       1      575
000596        000         22       1      585
000597        000         23       1      639
000598        000         24       1      835
000599        000         25       1      605
000600        000         26       1      557
000601        000         27       1      486
000602        000         28       1      515
000603        000         29       1      570
000604        000         30       1      618
```

REMAINDER OF **12,620**
CARD IMAGES CONTAINING
COSTS ARE TRUNCATED

APPENDIX D

THE FORTRAN IV SOURCE LANGUAGE LISTING OF THE TRIPUT AND TRANUV PROGRAMS AND THE SAMPLE PROBLEM OUTPUT

```
RUNID = 8590CA      FILE NAME = PRAGOOUTADCA      PART NUMBER = 00      DATE = 120671      DEVICE NAME =   RHEATH

01234567890123456789012345678901234567890123456789012345678901234567890123456789012345678901234567890123456789**SEQ NO. 01

@RUN,R/TPC TRIPUT,930-28-177,TRASH,10,175  . 8590CA   RHEATH1359911/C871

@SYM PRINT$,,RHEATH

@DELETE,C DISPOSE.
FURPUR 0220-12/06-13:57

@ASG,CP DISPOSE.,F/1/TRK/256

@DELETE,C TRUMP.
FURPUR 0220-12/06-13:57

@ASG,CP TRUMP.,F/1/TRK/256

@ASG,T 10.

@ASG,T8 TRIPIN,RF,5670

@USE 8.,TRIPIN


@FOR,IS DISPOSE.TRIPUT,.TRIPUT
FOR 19E-12/06/71-13:58:09 (,0)

   MAIN PROGRAM




STORAGE USED: CODE(1) 001111; DATA(0) 007516 PROGRAM

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)
[illegible]
```

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```
      DIMENSION NPOPOT(687),NTONS(687)
      DIMENSION NPOP(687)
      DIMENSION CINC(NC),DSLTFF(NC),NZONE(NC),COST3(NC)
      DIMENSION NCCNT(NC),VLAND(NC),CAPLF(NC),NACRES(NC),NVALS(NC)
      DIMENSION ITIME(687),NCIJ(687)
      DIMENSION NCOST(NC),COST1(NC),COST2(NC)
      IDTAPE=[illegible]
      NR=5
      NP=6
      ITW=10
      ITR=8
      NCENT=678
      READ(NR,1)N,LABORS,PAYLBR,DRDPAY,CSTHR,CAPLB,TRCAP,UNLOAD,WTMIN
    1 FORMAT(I[illegible],6F[illegible])
      READ(NR,2)(CINC(I),I=1,N)
    2 FORMAT(12F6.2)
      READ(NR,10)(DSLTFF(I),I=1,N)
   10 FORMAT(12F6.2)
      READ(NR,11)(VLAND(I),I=1,N)
   11 FORMAT(12F6.2)
      READ(NR,12)(CAPLF(I),I=1,N)
   12 FORMAT(12F6.2)
      READ(NR,13)(NACRES(I),I=1,N)
   13 FORMAT(12I6)
      READ(NR,14)(NZONE(I),I=1,N)
   14 FORMAT(12I6)
   15 FORMAT(12I6)
      READ(NR,15)(NPOPOT(I),I=1,NT)
      READ(NR,15)(NPOP(I),I=1,NT)
      WRITE(NP,4)
    4 FORMAT(1H1,'REFUSE DISPOSAL TRUCK INFORMATION')
      WRITE(NP,5)
    5 FORMAT(1H0,'HOURLY RATE        NUMBER    TRUCK CAP.    TRUCK COST')
      WRITE(NP,7)
    7 FORMAT(2X,'ONE DRIVER  LABORER   LABORERS      TONS        PER HO
     1UR')
      TRCST=CSTHR+DRDPAY+LABORS*PAYLBR
      WRITE(NP,8)DRDPAY,PAYLBR,LABORS,TRCAP,CSTHR
    8 FORMAT(1X,F6.2,F[illegible],I[illegible],F7.2,10X,F7.0,11X,F5.2)
      M=0
      J=1
      DO 80 I=1,NT
   16 IF(NZONE(J)-NPOPOT(I))18,17,18
   17 NCOST(J)=I
      J=J+1
      GO TO 16
   18 POP=NPOP(I)
      IF(POP)80,80,20
C     CALCULATE REFUSE GENERATED FROM ZONES IN TON/WK
   20 TONWK=POP*CAPLB*7./2000.
C     CALCULATE POPULATION TO GENERATE 1 TON OF REFUSE/WEEK
      POPMIN=WTMIN/(CAPLB*7.)
      IF(POP-POPMIN)80,70,70
   70 M=M+1
      NTONS(M)=TONWK
      NPOPOS(M)=NPOPOT(I)
      NNTONS=NNTONS+NTONS(M)
   80 CONTINUE
      NL=M-1
      WRITE(ITW,*)M,N
```

```
   85 FORMAT(8I7,I6)
      WRITE(ITW,85)(NTONS(I),I=1,M)
      WRITE(NP,60)M
   60 FORMAT(1X,' SUPPLY IN FILE WI',I4)
      TONSWK=NNTONS
      NSUM=0
      DO 90 I=1,N
      VALS=DSLTFF(I)*TONSWK
      NVALS(I)=VALS
   90 NSUM=NSUM+NVALS(I)
      NVALS(N)=NNTONS-NSUM
      WRITE(ITW,85)(NVALS(I),I=1,N)
      WRITE(NP,95)N
   95 FORMAT(1X,' DEMAND IN FILE WI',I4)
      DO 120 J=1,N
      V=NVALS(J)
      DSLTFF(J)=CAPLF(J)/(V*52.)
      IF(VLAND(J)-99.)100,110,100
  100 ACRES=NACRES(J)
      COST1(J)=VLAND(J)*ACRES/CAPLF(J)
      TONS=NVALS(J)
      TONDAY=TONS/6.
      X=TONDAY*.[illegible]
C     SOLVE EMPIRICAL EQUATION FOR COST OF LAND FILL OPERATION
      COST2(J)=[illegible]-1.7C512*X+.0510*X**2-.0002*X**3+.00005*X**4
      COST3(J)=COST1(J)+COST2(J)
      GO TO 120
  110 COST1(J)=0.
      COST2(J)=0.
      COST3(J)=CINC(J)
  120 CONTINUE
      M=0
      DO 190 J=1,N
  193 IF(NCOST(J)-M)195,196,195
  195 READ(IDTAPE,175)(ITIME(I),I=1,NCENT)
      M=M+1
      GO TO 193
  196 M=1
      DO 170 I=1,NT
      POP=NPOP(I)
      IF(POP)170,170,150
  150 TONWK=POP*CAPLB*7./2000.
      POPMIN=WTMIN/(CAPLB*7.)
      IF(POP-POPMIN)170,160,160
  160 TONS=NTONS(M)
      TRIPS=TONS/TRCAP
      HOURS=(TRIPS*ITIME(I)*2.)/60.+(UNLOAD* TRIPS)
      COST1=TRCST*HOURS/TONS
      CIJ=(COST1+COST3(J))*100.
      NCIJ(M)=CIJ
      M=M+1
  170 CONTINUE
      WRITE(ITW,175)(NCIJ(I),I=1,M)
  175 FORMAT(8I7,I9)
C     PRINTING OCCURS EACH TIME THAT COSTS ARE CALCULATED AND STORED
C     FROM ALL ZONES TO A DISPOSAL SITE
      WRITE(NP,178)NCOST(J)
```

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```
  170 FORMAT(1H0,'[illegible] NUMBER OF DISPOSAL SITE ZONE ',I3)
      WRITE(NPR,180)J
  180 FORMAT('0','TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE',I5)
  190 CONTINUE
      WRITE(LTW,195)(NZOPC(I),I=1,N)
  195 FORMAT([illegible])
      END FILE LTW
      END FILE LTW
  200 WRITE(NPR,210)
  210 FORMAT('1','                    REFUSE DISPOSAL SITE SYSTEM DATA')
      WRITE(NPR,220)
  220 FORMAT('0','MATRIX  TRANS AVG.WEEKLY  REGIONAL LANDFILL  LAND COST
     1  TOTAL        SITE LAND VAL REMAINING')
      WRITE(NPR,230)
  230 FORMAT(' COL NO.  ZONE  DISPOSAL     TOTAL    OPERATION    COST    D
     1ISPOSAL   COST   $ PER  CAPACITY')
      WRITE(NPR,240)
  240 FORMAT(' ','(TONS)     PERCENT  $ PER TON  $ PER TON $ PER TON YEAR
     1S   ACRE    (TONS)')
      WRITE(NPR,250)
  250 FORMAT(' ')
      DO 270 I=1,N
      PCT=PERCNT(I)*100.
      WRITE(NPR,260)I,NZONE(I),NVALS(I),PCT,COST2(I),COST1(I),COST4(I),
     1[illegible](I),VLAND(I),CAPL(I)
  260 FORMAT(I5,I8,I9,F11.2,F10.2,F11.2,F10.2,F8.1,F9.0,F10.0)
  270 CONTINUE
      WRITE(NPR,275)NNTONS
  275 FORMAT('0','TOTALS',I15)
      WRITE(NPR,280)
  280 FORMAT('1','                    MATRIX POSITION OF TRANSPORTATION ZONES')
      WRITE(NPR,290)
  290 FORMAT('0',10X,'0     1     2     3     4     5     6     7     8
     1     9')
      WRITE(NPR,300)
  300 FORMAT(' ')
      ITEM=0
      LL=M/10
      WRITE(NPR,310) ITEM,(NTOPOS(I),I=1,9)
  310 FORMAT(I6,I12,9I6)
      MM=10
      NN=19
      NSWITCH=1
  320 ITEM=ITEM+1
      IF(ITEM-LL)340,330,[illegible]
  330 NN=M
      NSWITCH=2
  340 WRITE(NPR,350)ITEM,(NTOPOS(I),I=MM,NN)
  350 FORMAT([illegible])
      MM=MM+10
      NN=NN+10
      GO TO (320,365),NSWITCH
  365 REWIND LTW
      STOP
      END

     END OF COMPILATION:          NO  DIAGNOSTICS.
```

```
@MAP,I DISPOSE.MAPTRI,DISPOSE.TRIPUT
MAP  [illegible]-12/05-13:53 -([illegible])

    1.        IN DISPOSE.TRIPUT




ADDRESS LIMITS    001000 012676      040000 054353
STARTING ADDRESS  011564

WORDS DECIMAL        5051 IBANK         5100 DBANK

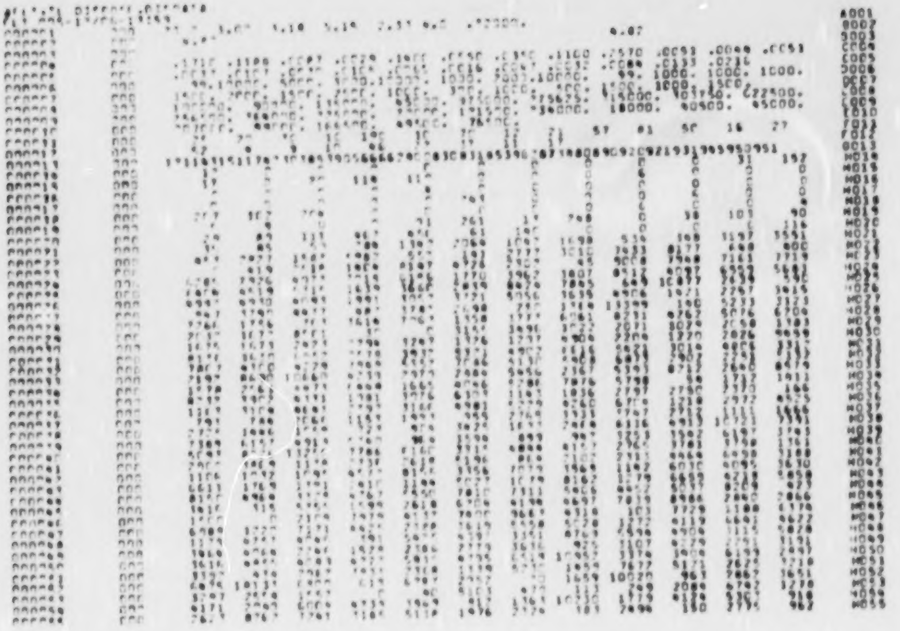

                  ELEMENT MAP              001000 012676       040000 054353

[illegible]                        1   001000 001132         2    040000 040035
[illegible]                        1   001133 001155
[illegible]                        1   001156 001402         2    040036 040175
[illegible]                                                  2    040176 042327
[illegible]                        1   001403 001572         2    042330 042365
[illegible]                        1   001573 001616
[illegible]                        1   001617 001755         0    042366 042370
[illegible]                        1   001756 002017
[illegible]                        1   002020 002065
[illegible]                        1   002066 002070
[illegible]                        1   002071 002201         2    042371 042433
[illegible]                        1   002202 002717         2    042434 042437
[illegible]                        1   002720 003720         2    042440 042474
[illegible]                        1   003721 004076         2    042475 042617
[illegible]                        1   004077 004302         2    042620 042634
[illegible]                        1   004303 005105         2    042635 042650
[illegible]                        1   005106 006024         2    042651 042731
[illegible]                        1   006025 006706         2    042732 043070
                                                             4    043071 043142
[illegible]                                                  2    043143 043201
[illegible]
[illegible]                        1   006707 006766         2    043202 043213
[illegible]                        1   006767 007356         2    043214 043371
[illegible]                        1   007357 007567         2    043372 043411
[illegible]                        1   007570 010126         0    043412 043413
                                                             2    043414 043500
[illegible]                        1   010127 010176
[illegible]                        1   010177 010267         2    043501 043633
[illegible]                        1   010270 010330
[illegible] (COMMON BLOCK)                                        043634 043650
[illegible]                        1   010331 011563         2    043651 044506
                                                             4    U0M5[illegible]
BLANK$COMMON (COMMON BLOCK)
TRIPUT                             1   011564 012676         0    044507 054353



                                                             2    BLANK$COMMON


[illegible], LEVEL [illegible]
END MAP  [illegible]
```



```
@RPT DISPOSE,OUTPUT

@ADD,P DISPOSE,DISDATA
                    REFUSE DISPOSAL TRUCK INFORMATION
        HOURLY RATE              NUMBER      TRUCK CAP.      TRUCK COST
  THE DRIVER  LABORER        LABORERS        TONS            PER HOUR

     5.18        5.00            2            8.                8.15
 SUPPLY IN FILE NO [illegible]
 DEMAND IN FILE NO [illegible]

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE      1

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE      2

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE      3

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE      4

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE      5

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE      6

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE      7

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE      8

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE      9

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     10

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     11

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     12

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     13

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     14

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     15
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```
CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     16

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     17

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     18

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     19

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     20

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     21

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     22

CENTROID NUMBER OF DISPOSAL SITE ZONE [illegible]
TRANSPORTATION COSTS CALCULATED FOR DISPOSAL SITE     23
                    REFUSE DISPOSAL SITE SYSTEM DATA

MATRIX  TRANS AVG.WEEKLY  REGIONAL LANDFILL  LAND SITE   TOTAL      SITE LAND VAL REMAINING
COL NO.  ZONE  DISPOSAL     TOTAL  OPERATION   COST     DISPOSAL    LIFE  $ PER   CAPACITY
               (TONS)     PERCENT  $ PER TON $ PER TON $ PER TON  YEARS   ACRE     (TONS)

   1      171    3000      17.10       .20        .30       4.87       .6      93.   100000.
   2      167    7312      33.48      1.08       2.73       3.31       .8   10000.    90000.
   3      151     156        .87      2.09       1.11       4.09     16.5    5000.   175000.
   4      178      51        .29      3.10        .83       3.85     17.0    3000.    93000.
   5      310    7089      16.00      1.00       1.94       3.03      7.3   10000.   976000.
   6      308     977       5.50      1.47        .06       1.57      2.5    1000.   273873.
   7      390     627       3.50      1.96        .06       2.01      5.7    3000.   315000.
   8      476    1955      11.00      1.10        .07       1.09      3.0   10000.   303750.
   9      662    6969      34.70   [illegible]    .22       4.92      2.6      93.   632300.
  10      810      96        .53   [illegible]    .23       3.39     56.8    1000.   336500.
  11      810      78        .88   [illegible]    .22       3.30     89.7    1020.   360000.
  12      811      96        .53   [illegible]    .24       3.27     88.1    1000.   275000.
  13      861      65        .37      3.12        .33       3.05     21.3    1800.    72000.
  14      812     190       1.07   [illegible]    .33       3.05     17.3    3000.   121500.
  15      823      53        .30      3.15        .33       3.76     86.9    1500.   336000.
  16      880     188       1.05   [illegible]    .46       3.96      3.9    2500.    10000.
  17      890     115        .65   [illegible]    .27       3.21      6.8    1020.    60500.
  18      920      78        .16   [illegible]    .27       3.28     50.7     300.    63000.
  19      921      83        .07   [illegible]    .27       3.24     68.7    1000.   707000.
  20      911      56        .32      3.18        .31       3.25     10.0     500.    99000.
  21      908     109        .08   [illegible]    .33       3.23     71.5    1500.   166500.
  22      850     736       1.73      2.65        .22       2.21      9.0    1000.    62500.
  23      841     497       5.16      2.97        .33       2.64      3.7    1000.    72500.

TOTALS          17783
```

```
                    MATRIX POSITION OF TRANSPORTATION ZONES
          0      1      2      3      4      5      6      7      8      9
    0           [illegible]
    [illegible]

    [illegible]

NORMAL EXIT.  EXECUTION TIME:        [illegible] MILLISECONDS.

@FREE [illegible].

@FILE,I TDUMP,[illegible]
[illegible]

@ADD,P IO.

@END
@END IGNORED - IN CONTROL MODE

@FREE TDUMP.

@ASG,A TDUMP.

@PRT,F TDUMP.
FURPUR [illegible]

   : : : :     PROJECT: TRACH          : : : :
   : : : :     ACCOUNT: [illegible]    : : : :
TRACH*TDUMP(1)-ASSIGNED
  [illegible]
  CATALOGUED PUBLIC

     MASS STORAGE USE                         EQUIP-GRANULES USED
   NO. OF GRANULES ASSIGNED:      [illegible]
   HIGHEST GRANULE ASSIGNED:      [illegible]
   HIGHEST TRACK REFERENCED:      [illegible]
   TOTAL ASSIGNMENTS:             [illegible]

   CATALOGUED     [illegible] DEC 1971  AT   [illegible]
   LAST REFERENCE 06 DEC 1971  AT   [illegible]

@PRT,T TDUMP.


TRACH*TDUMP ELEMENT TABLE
D  NAME          VERSION           TYPE          DATE          TIME      [illegible]   06 DEC 1971   AT   13:58:30
   [illegible]
   CATALOGUED  [illegible] DEC 1971  AT  [illegible]
   LAST REFERENCE ON DEC 1971  AT  [illegible]

[illegible]
FORTRAN PROCESSOR [illegible] TABLE [illegible]
ENTRY POINT TABLE [illegible]

[illegible]
[illegible]

   MAIN PROGRAM
   STORAGE USED: CODE(1) [illegible]; DATA(0) [illegible]; BLANK COMMON(2) [illegible]

   EXTERNAL REFERENCES (BLOCK, NAME)

    [illegible]

   STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

    [illegible]
    0000 I 001215 NDEST1     0000 I 001211 NORIG
    0000 I 001217 NROW       0000 I 001226 NROW1      0000 I 001232 NROW2


C     THIS PROGRAM SOLVES THE TRANSPORTATION PROBLEM BY THE MODI METHOD
C     DESCRIBED IN HADLEY'S LINEAR PROGRAMMING
C       IN THE FLOW CHART THAT ACCOMPANIES THIS PROGRAM THE FOUR-DIGIT
C     CARD AND BLOCK NUMBER CAN BE EQUATED TO STATEMENT NUMBERS BY THE
C     FOLLOWING REPLACEMENTS A=1 B=2 C=3 D=4 E=5 F=6 G=7 H=8 J=9 K=0


C       THE INITIAL BASIC FEASIBLE SOLUTION IS CREATED BY THE COLUMN
C     METHOD USING THE MINIMUM COST IN THE COLUMN TO CREATE THE NECESSARY
C     ENTRIES ON THE BASIS
C       THE PROGRAM WILL AUTOMATICALLY CREATE THE NECESSARY ROW SLACK OR
C     COLUMN SLACK AT HIGH COST TO ACCOUNT FOR INEQUALITY IN SUPPLY
C     AND DESTINATION
C     ****    *     *     *     *     *     * ****
      DIMENSION IBAS([illegible])
      DIMENSION ICOST([illegible])
      DIMENSION IU([illegible])
      DIMENSION IUI([illegible])
      DIMENSION IVI([illegible])
      DIMENSION IV([illegible])
      DIMENSION INET([illegible])
      DIMENSION INET1([illegible])
      DIMENSION INET2([illegible])
      DIMENSION IORIG([illegible])
      DIMENSION IDEST([illegible])
      DIMENSION [illegible]
      COMMON IBAS,ICOST,IU,IV,IUI,IVI,IORIG,IDEST
      EQUIVALENCE (IU(1),INET(1)),(IORIG(1),INET1(1)),(IDEST(1),INET2(1))
      NR=5
      NP=6
 1111 READ(NR,1)NORIG,NDEST
    1 FORMAT(2I3,F6[illegible])
 1121 M1=10**7
      M2=10**8
      NDEST1=NDEST
      NORIG1=NORIG
 1131 READ(NR,11)(NROW,IORIG(NROW),I=1,NORIG)
 1141 READ(NR,11)(NCOL,IDEST(NCOL),I=1,NDEST)
 1151 DO 101 I=1,NORIG
      DO 101 J=1,NDEST
  101 ICOST(I,J)=0
 1161 READ(NR,2)((NROW,NCOL,ICOST(NROW,NCOL),I=1,NORIG),J=1,NDEST)
    2 FORMAT([illegible])
      READ(NR,1)([illegible](I),I=1,NORIG)
   11 FORMAT([illegible])
 1171 ISUMO=0
      ISUMD=0
      DO 102 I=1,NORIG
  102 ISUMO=ISUMO+IORIG(I)
      DO 103 J=1,NDEST
  103 ISUMD=ISUMD+IDEST(J)
 1181 IF(ISUMO-ISUMD)1115,1112,1191
 1191 NDEST=NDEST+1
      IDEST(NDEST)=ISUMO-ISUMD
 1101 DO 104 I=1,NORIG
  104 ICOST(I,NDEST)=999999
      GO TO 1112
 1115 NORIG=NORIG+1
      IORIG(NORIG)=ISUMD-ISUMO
 1125 DO 105 J=1,NDEST
  105 ICOST(NORIG,J)=999999
 1112 DO 106 I=1,NORIG
      DO 106 J=1,NDEST
  106 IBAS(I,J)=0
 1129 NCOL=1
      NROW=1
      ISAV=M
      DO 107 I=1,NORIG
  107 IU(I)=1
      DO 108 J=1,NDEST
  108 IV(J)=1
 1162 IF(ICOST(NROW,NCOL)-ISAV)1172,1169,1163
 1163 NROW=NROW+1
 1173 IF(NROW-NORIG)1162,1162,1167
 1172 IF(IU(NROW)-1)1163,1167,1163
 1169 ISAV=ICOST(NROW,NCOL)
      NROW1=NROW
      GO TO 1163
 1167 IF(IORIG(NROW1)-IDEST(NCOL))1174,1173,1164
 1174 IBAS(NROW1,NCOL)=IORIG(NROW1)+M
 1178 IDEST(NCOL)=IDEST(NCOL)-IORIG(NROW1)
      IU(NROW1)=0
      NROW=1
      ISAV=M
      GO TO 1162
 1173 IBAS(NROW1,NCOL)=IORIG(NROW1)+M
      IU(NROW1)=0
      NROW=1
      ISAV=M
      IF(NCOL-NDEST)1187,1211,1211
 1187 IF(ICOST(NROW,NCOL)-ISAV)1193,1197,1197
 1193 IF(IU(NROW)-1)1197,1183,1197
 1183 ISAV=ICOST(NROW,NCOL)
      NROW1=NROW
 1197 NROW=NROW+1
      IF(NROW-NORIG)1187,1187,1176
 1176 IBAS(NROW1,NCOL)=M
      NCOL=NCOL+1
 1180 IF(NCOL-NDEST)1190,1190,1211
 1190 NROW=1
      ISAV=M
      GO TO 1187
 1164 IBAS(NROW1,NCOL)=IDEST(NCOL)+M
      IORIG(NROW1)=IORIG(NROW1)-IDEST(NCOL)
 1165 NCOL=NCOL+1
      GO TO 1180
C     NOW THAT A BASIC FEASIBLE SOLUTION HAS BEEN DETERMINED IT IS NECESSARY
C     TO CALCULATE THE SHADOW COSTS AND THE [illegible] GREATER THAN ZERO
C     TO DETERMINE WHETHER THE SOLUTION IS OPTIMAL AND [illegible] GREATER
C     THAN ZERO). IF NON-OPTIMAL THE NEW ELEMENT IS THE ONE WITH THE
C     LARGEST Z-C. IF OPTIMALITY EXISTS THE PROGRAM EXITS TO THE
C     OUTPUT ROUTINE
 1211 DO 109 I=1,NORIG
      IU(I)=0
  109 IU1(I)=0
      DO 110 J=1,NDEST
      IV(J)=0
  110 IV1(J)=0
 1221 IU1(1)=1
      NROW=1
      NCOL=1

 1731 IF(IBAS(NROW,NCOL)-M)1737,1701,1701
 1701 IV(NCOL)=ICOST(NROW,NCOL)-IU(NROW)
      IV1(NCOL)=1
 1737 NCOL=NCOL+1
 1747 IF(NCOL-NDEST)1731,1731,1757
 1757 NROW=NROW+1
 1767 IF(NROW-NORIG)1777,1777,1761
 1777 IF(IU1(NROW)-1)1757,1757,1787
 1787 NCOL=1
 1797 IF(IBAS(NROW,NCOL)-M)1807,1763,1763
 1807 NCOL=NCOL+1
 1817 IF(NCOL-NDEST)1797,1797,1757
 1763 IF(IV1(NCOL))1773,1807,1773
 1773 IU(NROW)=ICOST(NROW,NCOL)-IV(NCOL)
      IU1(NROW)=1
 1783 NCOL=1
      GO TO 1731
 1761 NROW=1
 1771 IF(IU1(NROW))1791,1781,1791
 1781 NROW=NROW+1
 1791 IF(NROW-NORIG)1771,1771,1713
 1713 ISAV=0
      NROW=1
 1723 NCOL=1
 1733 IF(IBAS(NROW,NCOL)-M)1796,1703,1703
 1703 NCOL=NCOL+1
 1753 IF(NCOL-NDEST)1733,1733,1756
 1756 NROW=NROW+1
 1766 IF(NROW-NORIG)1723,1723,1776
 1776 IF(ISAV)1311,1311,1311
 1796 IS1=IU(NROW)+IV(NCOL)-ICOST(NROW,NCOL)
 1786 IF(IS1-ISAV)1703,1703,1795
 1795 ISAV=IS1
      NROW1=NROW
      NCOL1=NCOL
      GO TO 1703
C     THIS SECTION IS ENTERED ON EVERY NON-OPTIMAL ITERATION IT FINDS
C     THE LOOP IN THE MATRIX CONTAINING THE NEW ELEMENT AND ELEMENTS IN
C     THE CURRENT BASIS. IF NO LOOP EXISTS AN ERROR MESSAGE IS PRINTED.
 1311 K=(NORIG+NDEST)*2
      DO 111 I=1,K
  111 INF1(I)=0
      DO 112 I=1,NORIG
  112 INF2(I)=0
      DO 113 I=1,NDEST
  113 INF3(I)=0
      I=1
 1321 INF1(I)=NROW1
      INF1(I+1)=NCOL1
      NROW=NROW1
      NCOL=1
      I=I+2
 1331 IF(IBAS(NROW,NCOL)-M)1371,1361,1361
 1361 IF(NCOL-NCOL1)1391,1372,1391
 1391 INF1(I)=NROW
      INF1(I+1)=NCOL
      I=I+2
      GO TO 1911
 1305 NCOL=NCOL+1
 1310 IF(NCOL-NDEST)1316,1311,1312
 1312 I=1
      WRITE(NPR,111)NROW1,NCOL1
    1 FORMAT(13H ERROR NUMBER,I6,I6,I6)
      GO TO 1511
 1317 INFT(2)=NCOL+1
      NROW=1
 1320 IF(IRA(NROW,NCOL)-M)1325,1330,1320
 1325 NROW=NROW+1
 1327 IF(NROW-NORIG)1320,1320,1399
 1329 I=I-2
 1363 IF(I)1315,1319,1319
 1330 NROW=INFT(I)
      NCOL=INFT(I+1)
      INFT(INCOL)=0
      GO TO 1325
 1319 I=2
      WRITE(NPR,111)NROW1,NCOL1
      GO TO 1511
 1330 IF(NROW-INFT(I-1))1330,1331,1330
 1336 IF(INFT(INROW))1353,1366,1353
 1366 INFT(I)=NROW
      INFT(I+1)=NCOL
      I=I+2
 1350 IF(NROW-NROW1)1350,1355,1360
 1355 I=I-2
      GO TO 1399
 1366 INFT(INROW)=1
      NCOL=1
 1370 IF(IRA(NROW,NCOL)-M)1375,1380,1380
 1375 NCOL=NCOL+1
 1377 IF(NCOL-NDEST)1370,1370,1371
 1380 IF(NCOL-INFT(I-1))1390,1375,1390
 1390 IF(INFT(INCOL))1371,1366,1371
 1387 INFT(I)=NROW
      INFT(I+1)=NCOL
      I=I+2
 1370 IF(NCOL-NCOL1)1311,1911,1311
 1371 I=I-2
 1381 IF(I)1319,1319,1387
 1387 NROW=INFT(I)
      NCOL=INFT(I+1)
      INFT(INROW)=0
      GO TO 1375
C     AT THIS TIME WE HAVE FOUND A VALID LOOP IN WHICH ALL MOVES ARE
C     ORTHOGONAL AND SHALL NOW FIND THE SMALLEST ELEMENT IN THE LOOP
C     WHICH IS REACHED IN AN ODD NUMBER OF MOVES FROM THE ENTERING
C     ELEMENT. THIS IS THE ELEMENT WHICH WILL LEAVE
 1911 I=3
      ISAV=M
 1921 NROW=INFT(I)
      NCOL=INFT(I+1)
 1931 IF(IRA(NROW,NCOL)-ISAV)1932,1941,1941
 1932 ISAV=IRA(NROW,NCOL)
      NROW2=NROW
```

```
      NCOL2=NCOL
 1941 IF(NCOL-NCOL1)1951,1962,1951
 1951 I=I+4
 1961 IF(I-M)1921,1921,1971
 1971 I=3
      WRITE(NPR,111)NROW1,NCOL1
      GO TO 1511
 1962 IF(ISAV-M)1967,1952,1952
 1967 I=4
      WRITE(NPR,111)NROW1,NCOL1
      GO TO 1511
 1952 J=-1
      NROW=INFT(1)
      NCOL=INFT(2)
      IRA(NROW,NCOL)=ISAV
      ISAV=ISAV-M
      I=3
 1955 NROW=INFT(I)
      NCOL=INFT(I+1)
 1957 IF(NROW-NROW2)1963,1958,1963
 1958 IF(NCOL-NCOL2)1963,1959,1963
 1959 IRA(NROW,NCOL)=0
      GO TO 1973
 1963 IRA(NROW,NCOL)=IRA(NROW,NCOL)+J*ISAV
 1973 J=-J
      I=I+2
 1983 IF(NCOL-NCOL1)1955,1211,1955
C     THE NEXT ROUTINE IS THE OUTPUT ROUTINE. IT IS REACHED EITHER WHEN
C     AN OPTIMUM SOLUTION IS FOUND OR WHEN AN ERROR OCCURS AND THE OUTPUT
C     PART OF INTEREST. IN CASE OF AN ERROR THE SHADOW PRICES REPRESENT
C     COORDINATES OF THE BASIS LOOP CALCULATIONS
 1511 WRITE(NPR,4)
    4 FORMAT(1H1,27HORIGIN      SHADOW PRICE)
    5 FORMAT(1H I5,I16)
 1521 WRITE(NPR,5)(I,U(I),I=1,NORIG)
 1531 WRITE(NPR,6)
    6 FORMAT(27H1DESTIN      SHADOW PRICE)
 1541 WRITE(NPR,5)(J,V(J),J=1,NDEST)
 1551 WRITE(NPR,7)
    7 FORMAT(55H1ZONE ORIGIN   DESTIN  QUANTITY   UNIT COST  TOTAL COST)
      ITIS=0
 1561 DO 110 I=1,NORIG
      DO 110 J=1,NDEST
      IF(IRA(I,J)-M)110,115,115
  115 ITEM=IRA(I,J)-M
      ITEM1=ICOST(I,J)
      ITEM2=ITEM*ITEM1
      WRITE(NPR,8)NZORG(I),I,J,ITEM,ITEM1,ITEM2
    8 FORMAT(1H ,I6,I7,I9,I10,I17,I12)
  110 CONTINUE
 1571 WRITE(NPR,7)
 1581 DO 118 J=1,NDEST
      IQUAN=0
      JCOST=0
      DO 116 I=1,NORIG
      IF(IRA(I,J)-M)116,117,117
  117 ITEM=IRA(I,J)-M
```

```
[illegible]
                 116 CONTINUE
[illegible]
                 110 CONTINUE
[illegible]
                     END
      END OF COMPILATION:        NO  DIAGNOSTICS.

@MAP,I DISPOSE.TRANMAP,DISPOSE.TRANSOT
MAP  [illegible]

    1.      IN DISPOSE.TRANUV


ADDRESS LIMITS    001000 013010      040000 146522
STARTING ADDRESS  011216

WORDS DECIMAL       5129 IBANK       35179 DBANK

              SEGMENT MAIN            001000 013010      040000 146522
[illegible]
BLANK$COMMON (COMMON BLOCK)
TRANUV                        1   011216 013010        145160 146522
                                                       BLANK$COMMON


SYS$*RLIB$. LEVEL [illegible]
END MAP  [illegible]

@XQT DISPOSE.TRANSOT

@ADD,P [illegible]

ORIGIN    SHADOW PRICE
[illegible]
```

DEPTH SHADOW PRICE

[illegible]

```
ZONE ORIGIN   DESTIN  QUANTITY   UNIT COST  TOTAL COST
```

[illegible]

ROW	ORIGIN	DESTIN	QUANTITY	UNIT COST	TOTAL COST
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

DEST. TOTAL

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```
[illegible]
[illegible]
[illegible]
DEPT. TOTALS [illegible]
[illegible]
[illegible]
[illegible]
DEPT. TOTALS [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
DEPT. TOTALS [illegible]
[illegible]
[illegible]
[illegible]
DEPT. TOTALS [illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
[illegible]
DEPT. TOTALS [illegible]
REGION TOTALS [illegible]
```

```
NORMAL EXIT.  EXECUTION TIME:       [illegible] MILLISECONDS.

[illegible]

    RUNID:  [illegible]   ACCOUNT: [illegible]     PROJECT: TRASH
      [illegible]
    TIME: [illegible]    IN: [illegible]  OUT: [illegible]        PAGES:  [illegible]
    MEMORY TIME: [illegible]
    INITIATION  TIME:  [illegible]-DEC  8,1971
    TERMINATION TIME:  [illegible]-DEC  8,1971
```

COST OPTIMIZED REFUSE DISPOSAL SITE SERVICE AREAS

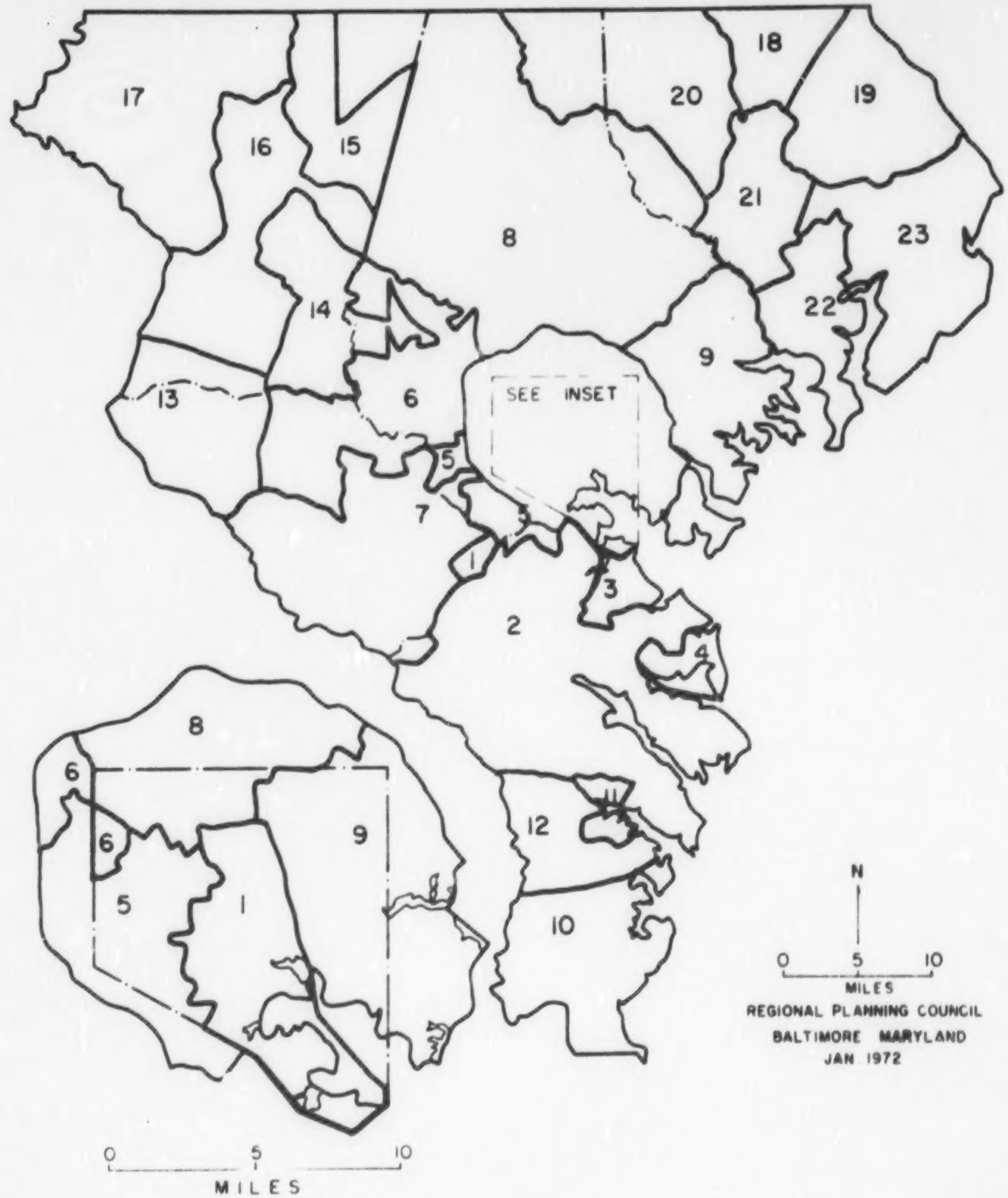
17
16
15
18
20
19
21
8
23
14
22
9
13
6
SEE INSET
5
7
1
3
2
4
8
6
6
9
12
11
5
1
10
N
0
5
10
MILES
REGIONAL PLANNING COUNCIL
BALTIMORE MARYLAND
JAN 1972
0
5
10
MILES

FIGURE 27

APPENDIX E

DOCUMENTATION OF THE TRANSPORTATION PROBLEM
FROM THE IBM 360 PROGRAM LIBRARY
IN FORTRAN IV

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TRANSPORTATION PROBLEM

John S. Segal

June 20, 1966

Direct Inquiries to: Mr. John S. Segal
IBM Corporation
222 Mamaroneck Avenue
White Plains, N. Y. 10601

Correction: February 1969

I. Table of Contents

Abstract 3
User Information 4
Operating Instructions 5
Deck Key 7
Flow Charts 8
Listings 13
Sample Problem 29

Corrected: July 68

II. Abstract

This problem solves the warehouse-distributor type of Transportation problem by the MODI method described in Linear Programming, pp. 273-312 by G. Hadley, Addison-Wesley Publishing Company, using a column minima to generate an initial feasible solution. Column or row slack necessitated by inequality of availability and requirements is automatically generated. Programming language is DOS FORTRAN. Machine requirements are any /360 with at least 32K core. Actual core required depends on problem size.

3

III. User Information

This program will solve the warehouse-distributor type transportation; i.e., for a given number of warehouses each with a supply, S_i, and a number of customers each with requirements, R_j, and I x J costs, C_{ij}, of moving one unit of product from warehouse i to customer j, find the minimum cost of moving the goods. The method used is the MODI method with column minimum costs as described in Hadley's Linear Programming (Addison-Wesley) pp. 273-312.

The program is written in Fortran with IBM System/360 Disk Operating System. The amount of core available for data storage is Max Core - $17,100_{10} = C_A$. If I is the number of warehouses and J the number of destinations the problem size is approximated by $C_A/8 \quad I * J + 3I + 3J$. Since an extra row or column is automatically generated when there is an inequality between the amount required and the amount available an extra row and/or column is always available for use. Fixed-point arithmetic is used throughout.

There is one modification which must be done in order to run this program - - the dimension statements must be set up in the following manner:

```
IBAS ( I + 1,  J + 1)
ICOST (I + 1,  J + 1)
IU (I + 1)
IV (J + 1)
IU1 (I + 1)
IV1 (J + 1)
INET ( 2I + 2J + 2)
INET1 (I + 1)
INET2 (J + 1)
IORIG (I + 1)
IDEST ( J + 1)
```

I = number of origins
J = number of destinations
At Statement 1121 K1 and K2 must be set so that K1>> largest origin availability or destination requirement and K2 = 10K1.

IV. Operating Instructions

This program uses no switch settings of any sort nor does it depend on any initial machine conditions. It can be run as compile-and-go or from the core image library.

The following is a description of the Input Data. All input is in Fortran 17 format.

a. Problem Size Card
   cc 1-7 # of origins
   cc 8-14 # of destinations

b. Origin Information (1 card/origin)
   cc 1-7 Origin number
   cc 8-14 Availability (units)

c. Destination Information (1card/destination)
   cc 1-7 Destination number
   cc 8-14 Requirements (units)

d. Cost Deck (total number of cards = # origins x # destinations)
   cc 1-7 Origin number
   cc 8-14 Destination number
   cc 15-21 Transportation Cost per unit

e. / * Card

There are four sets of output on both SYSLST and SYSPCH.

a. Shadow Costs for origins
b. Shadow Costs for destinations
c. Solution in origin sequence
d. Solution in destination sequence.

There are four errors detected by the program. None should occur on any problem. If one of them should occur the shadow cost output is meaningless, but the solution is the current best solution.

Error 1:	No basis element in row which contains entering element in an iteration.
Error 2:	There is no basis loop.
Error 3:	The basis loop has more elements than there are in the basis.
Error 4:	There is no element in the basis loop less than K2.

The carriage tape should have a '1' punch and a '12' punch. These are the only channels used by the program.

V. Deck Key

Deck I is the source deck with appropriate control cards for compile and execute. 307 Cards

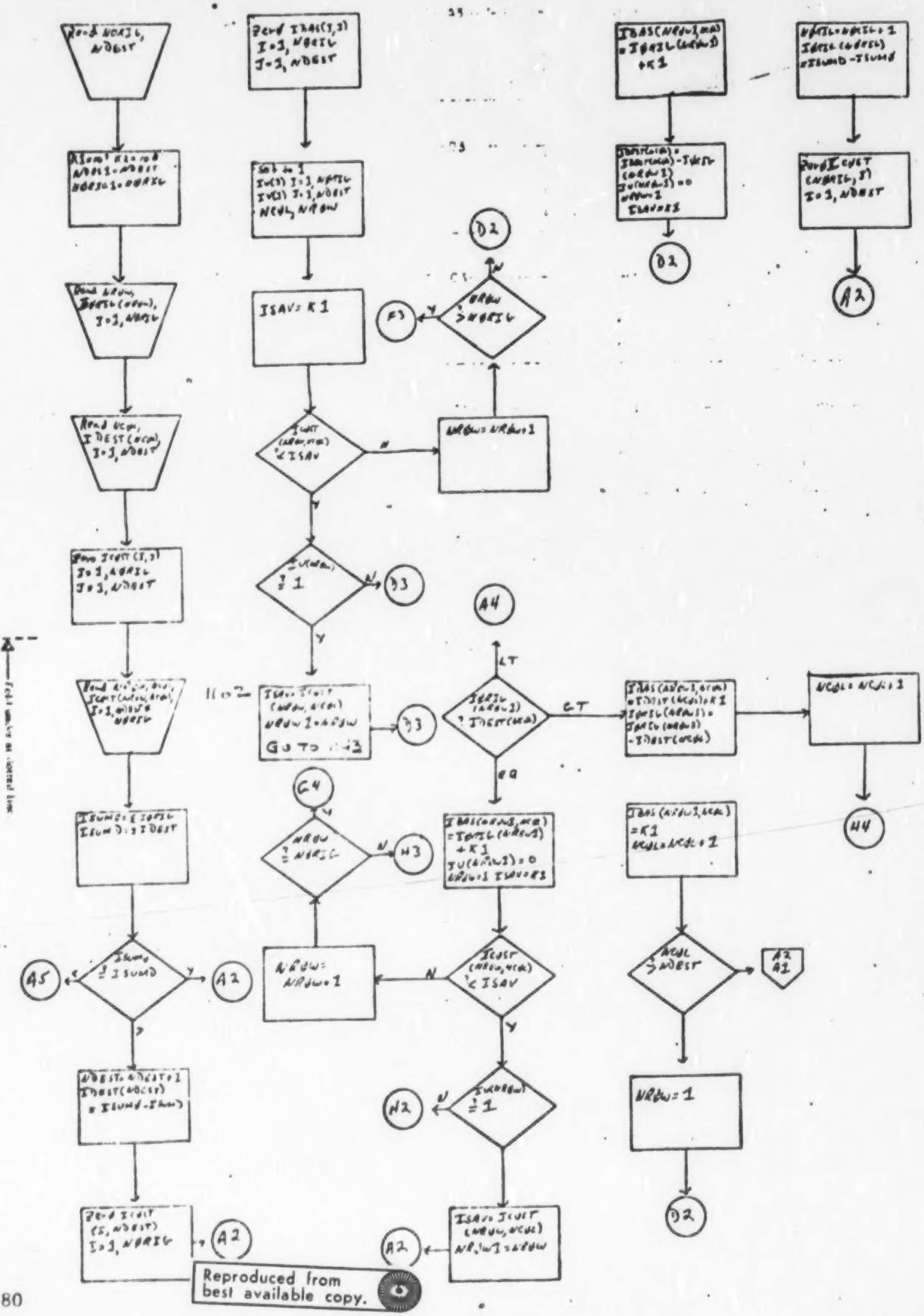
Deck II is the sample problem data deck. 723 Cards

There is no sequence number or identification punched in the cards.

Corrected:July 68

IBM Flowcharting Worksheet

Programmer: J. S. Segal
Program No.:
Date: 6/8/66
Page: A1
Chart ID:
Chart Name: Initialization - Form Basic Feasible Sol.
Program Name: TRANSportation Program


Read NORIG, NDEST
ISAV=K1
D2
F3
Y
N
NROW=NROW+1
D3
A4
LT
GT
EQ
GO TO H3
G4
H3
NROW ≥ NORIG
ISUMO = Σ IORIG
ISUMD = Σ IDEST
A5
A2
ISUMO = ISUMD
NROW = NROW+1
ICOST (NROW, NCOL) < ISAV
H2
NCOL = NCOL+1
NCOL ≥ NDEST
A2
A1
NROW=1
D2
NDEST=NDEST+1
ISAV=ICOST (NROW, NCOL)
NORIG=NORIG+1
ISUMD-ISUMO
Read ICOST
I=1, NDEST
I=1, NORIG

Fold under at dotted line.

Fold under at dotted line.

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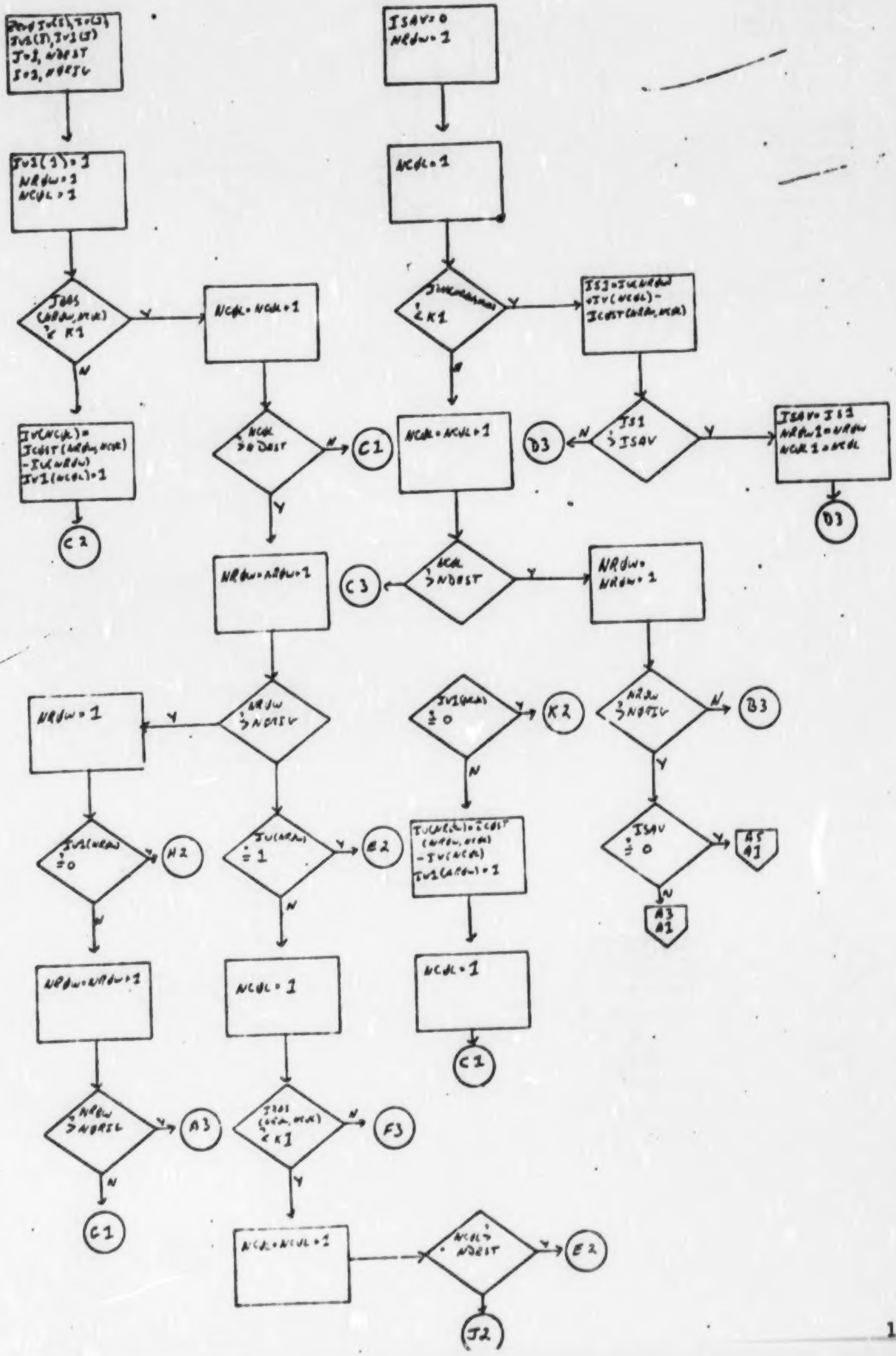
IBM Flowcharting Worksheet

Programmer: J. S. Segal
Program No.:
Date: 6/8/66
Page: A 2
Chart ID:
Chart Name: Calculate Shadow Costs, Z$_{ij}$ - C$_{ij}$
Program Name: TRANSPORTATION Program

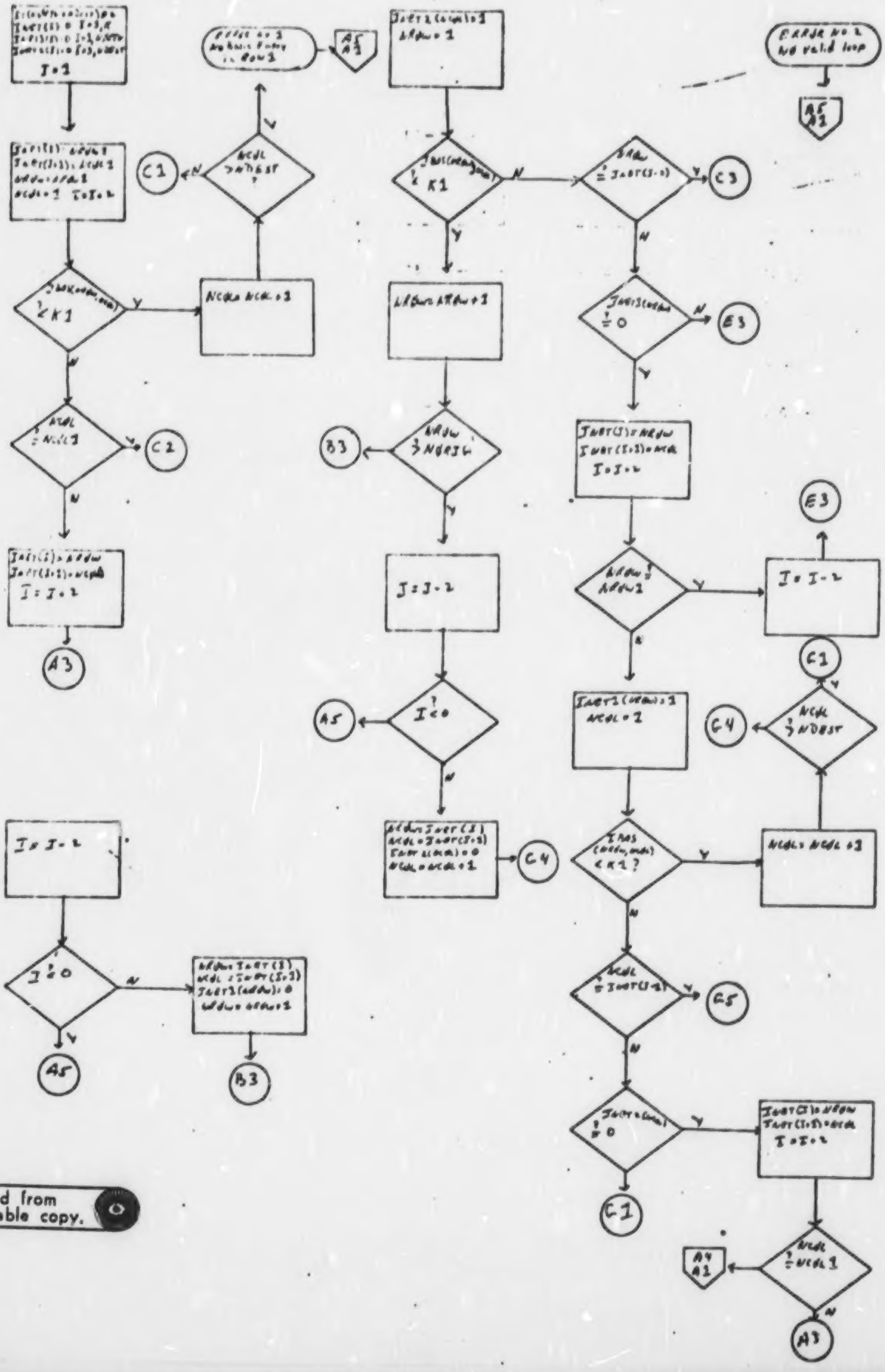


Read IV(I), IV(J), IV1(I), IV1(J), J=1, NDEST, I=1, NORIG
IV1(1)=1
NROW=1
NCOL=1
IBAS (NROW, NCOL) ≥ K1
Y
N
IV(NCOL)= ICOST(NROW, NCOL) - IU(NROW)
IV1(NCOL)=1
C2
NCOL=NCOL+1
NCOL ≥ NDEST
N
C1
Y
NROW=NROW+1
NROW ≥ NORIG
Y
NROW=1
IV1(NROW) = 0
H2
N
NROW=NROW+1
NROW ≥ NORIG
A3
C1
IU(NROW) = 1
E2
NCOL=1
IBAS (NROW, NCOL) < K1
F3
NCOL=NCOL+1
NCOL ≥ NDEST
E2
J2
ISAV=0
NROW=1
NCOL=1
≤ K1
ISI=IU(NROW) +IV(NCOL)- ICOST(NROW, NCOL)
ISI ≥ ISAV
D3
ISAV=ISI
NROW1=NROW
NCOL1=NCOL
D3
NCOL=NCOL+1
C1
NCOL ≥ NDEST
C3
NROW= NROW+1
NROW ≥ NORIG
B3
IV1(NCOL) = 0
K2
IU(NROW)=ICOST (NROW, NCOL) - IV(NCOL)
IU1(NROW)=1
NCOL=1
C1
ISAV = 0
A5
A1
A3
A1

Flowcharting Worksheet

Programmer: J S Segel Program No.: Date: 6/8/66 Page: A3

Chart ID: Chart Name: Find Basis Loop Program Name: TRANSPORTATION Program



I = 1
ERROR NO 1
No Basic Entry in Row 1
A5
A1
ERROR NO 2
NO valid loop
A5
A1
K1
C1
N
Y
NCOL = NCOL + 1
K1
N
C3
Y
NCOL > NDEST ?
N
Y
C2
N
E3
A3
B3
Y
J = J - 2
E3
I = I - 2
C1
A5
I < 0
C4
NDEST
N
Y
C4
I = I - 2
I = 0
N
Y
A5
B3
C5
N
C1
A4
A1
N
A3

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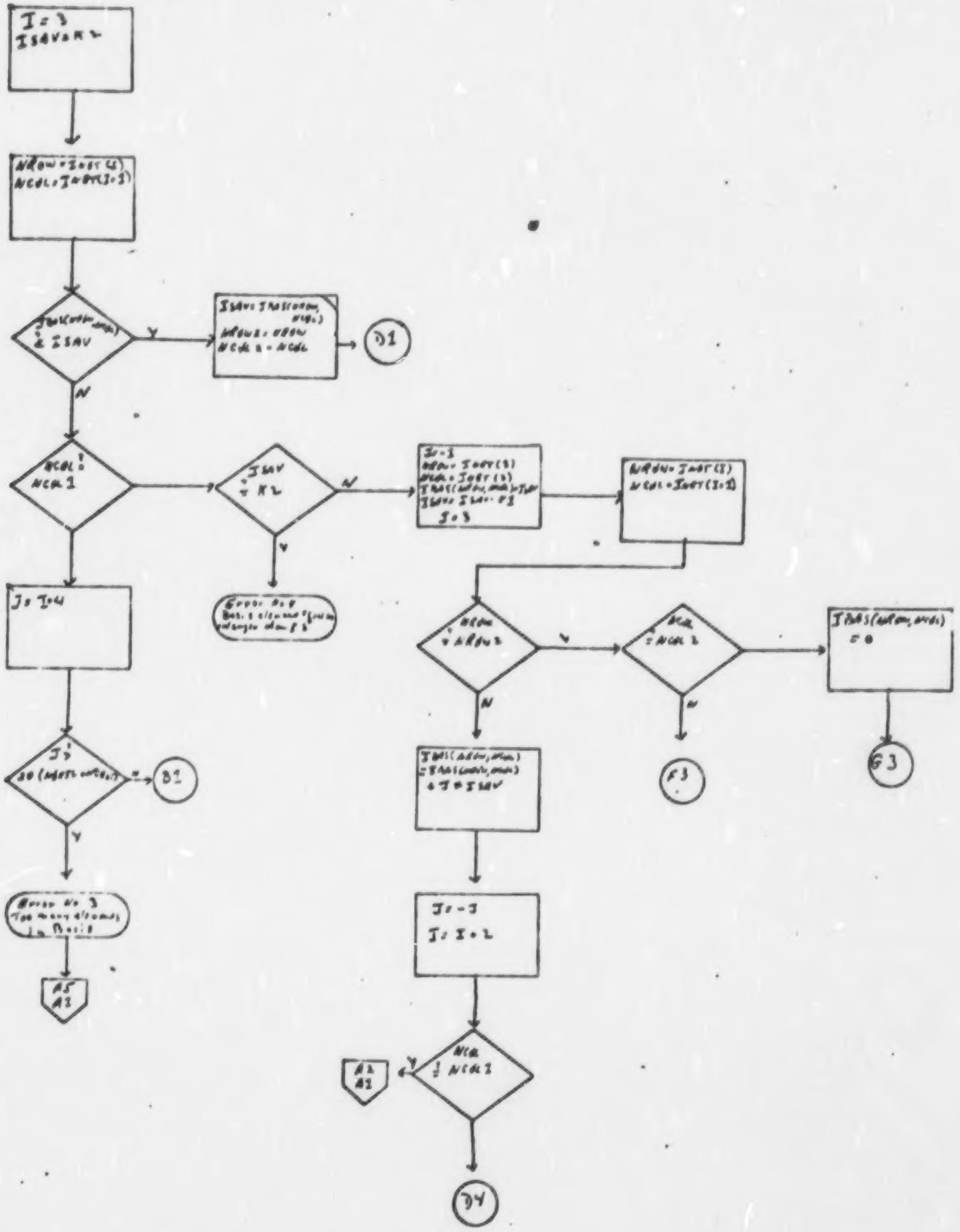
IBM Flowcharting Worksheet

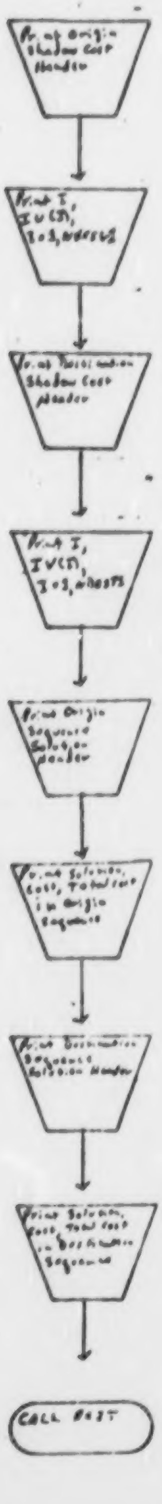
Programmer: I. S. Segal Program No.: Date: 6/B/66 Page: A4

Chart ID: Chart Name: Modify Basis Routine Program Name: Transportation Program


I = 3
ISAV = K2
NROW = IORT(4)
NCOL = IORT(I+1)
& ISAV
Y
N
ISAV = IBAS(NROW, NCOL)
NROW2 = NROW
NCOL2 = NCOL
D1
NCOL : NCOL1
ISAV : K2
N
Y
Error No 4
J = I + 4
I : 20
B1
Y
Error No 3
Too many elements in Basis
A5
A1
NROW : NROW2
NCOL2
IBAS(NROW, NCOL)
= 0
F3
G3
J = I + 2
NCOL : NCOL1
A2
A1
D4

IBM Flowcharting Worksheet

Programmer: J. S. Segal Program No.: Date: 6/8/66 Page: A5
Chart ID: Chart Name: OUTPUT Routine Program Name: TRANSPORTATION Program


Print Origin Shadow Cost Header
Print I, IV(I), I=1,NORGNS
Print Destination Shadow Cost Header
Print I, IV(I), I=1,NDESTS
Print Origin Sequence Solution Header
Print Solution, Cost, Total Cost in Origin Sequence
Print Destination Sequence Solution Header
Print Solution, Cost, Total Cost in Destination Sequence
CALL EXIT

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```
C     THIS PROGRAM SOLVES THE TRANSPORTATION PROBLEM BY THE MODI METHOD
C     DESCRIBED IN HADLEY@S LINEAR PROGRAMMING¤.
C       IN THE FLOW CHART THAT ACCOMPANIES THIS PROGRAM THE FOUR-DIGIT
C     PAGE AND BLOCK NUMBER CAN BE EQUATED TO STATEMENT NUMBERS BY THE
C     FOLLOWING REPLACEMENTS A01 B02 C03 D04 E05 F06 G07 H08 J09 K10
C       THE INITIAL BASIC FEASIBLE SOLUTION IS CREATED BY THE COLUMN
C     METHOD USING THE MINIMUM COST IN THE COLUMN TO CREATE THE NECESSARY
C     ENTRIES ON THE BASIS.
C       THE PROGRAM WILL AUTOMATICALLY CREATE THE NECESSARY ROW SLACK OR
C  COLUMN SLACK AT HIGH COST TO ACCOUNT FOR INEQUALITY IN SUPPLY
C   AND DESTINATION
C     ****   *   *   *   *   *   *   *   *   *   *   ********
      DIMENSION IBAS%20,60¤
      DIMENSION ICOST%20,60¤
      DIMENSION IU%20¤
      DIMENSION IU1%20¤
      DIMENSION IV1%60¤
      DIMENSION IV%60¤
      DIMENSION INET%2731¤
      DIMENSION INET1%120¤
      DIMENSION INET2%300¤
      DIMENSION IORIG%20¤
      DIMENSION IDEST%60¤
      COMMON IBAS,ICOST,IU,IV,IU1,IV1,IORIG,IDEST
      EQUIVALENCE%%IU%1¤,INET%1¤¤,%IORIG%1¤,INET1%1¤¤,%IDEST%1¤,INET2%1¤¤
      NR#1
      NP#2
       NPR#3
 1111 READ%NR,1¤NORIG,NDEST
    1 FORMAT%2I3¤
 1121 B1#10¤¤7
      B2#10¤¤8
      NDEST1#NDEST
      NORIG1#NORIG
 1131 READ%NR,1¤%NROW,IORIG%NROW¤,I#1,NORIG¤
 1141 READ%NR,1¤%NCOL,IDEST%NCOL¤,I#1,NDEST¤
 1151 DO 101 I#1,NORIG
      DO 101 J#1,NDEST
  101 ICOST%I,J¤#0
 1161 READ%NR,2¤%%NROW,NCOL,ICOST%NROW,NCOL¤,I#1,NORIG¤,J#1,NDEST¤
    2 FORMAT%3I3¤
 1171 ISUMO#0
      ISUMD#0
      DO 102 I#1,NORIG
  102 ISUMO#ISUMO&IORIG%I¤
      DO 103 J#1,NDEST
  103 ISUMD#ISUMD&IDEST%J¤
 1101 IF%ISUMD-ISUMO¤1119,1112,1191
 1191 NDEST#NDEST&1
      IDEST%NDEST¤#ISUMO-ISUMD
 1101 DO 104 I#1,NORIG
  104 ICOST%I,NDEST¤#99999999
      GO TO 1112
 1119 NORIG#NORIG&1
```

13

```
07/26/68          FORTMAIN                                              0002
      IORIG%NORIG¤#ISUMD-ISUMO
 1129 DO 105 J#1,NDEST
  105 ICOST%NORIG,J¤#99999999
 1112 DO 106 I#1,NORIG
      DO 106 J#1,NDEST
  106 IBAS%I,J¤#0
 1122 NCOL#1
      NROW#1
      ISAV#B1
      DO 107 I#1,NORIG
  107 IU%I¤#1
      DO 108 J#1,NDEST
  108 IV%J¤#1
 1142 IF%ICOST%NROW,NCOL¤-ISAV¤1152,1143,1143
 1143 NROW#NROW&1
 1133 IF%NROW-NORIG¤1142,1142,1163
 1152 IF%IU%NROW¤-1¤1143,1167,1143
 1167 ISAV#ICOST%NROW,NCOL¤
      NROWL#NROW
      GO TO 1143
 1163 IF%IORIG%NROWL¤-IDEST%NCOL¤¤1116,1173,1184
 1116 IBAS%NROWL,NCOL¤#IORIG%NROWL¤&B1
 1126 IDEST%NCOL¤#IDEST%NCOL¤-IORIG%NROWL¤
      IU%NROWL¤#0
      NROW#1
      ISAV#B1
      GO TO 1142
 1173 IBAS%NROWL,NCOL¤#IORIG%NROWL¤&B1
      IU%NROWL¤#0
      NROW#1
      ISAV#B1
      IF%NCOL-NDEST¤1183,1211,1211
 1183 IF%ICOST%NROW,NCOL¤-ISAV¤1193,1102,1102
 1193 IF%IU%NROW¤-1¤1102,1103,1102
 1103 ISAV#ICOST%NROW,NCOL¤
      NROWL#NROW
 1102 NROW#NROW&1
      IF%NROW-NORIG¤1183,1183,1174
 1174 IBAS%NROWL,NCOL¤#B1
      NCOL#NCOL&1
 1186 IF%NCOL-NDEST¤1194,1194,1211
 1194 NROW#1
      ISAV#B1
      GO TO 1142
 1184 IBAS%NROWL,NCOL¤#IDEST%NCOL¤&B1
      IORIG%NROWL¤#IORIG%NROWL¤-IDEST%NCOL¤
 1185 NCOL#NCOL&1
      GO TO 1194
C     NOW THAT A BASIC FEASIBLE SOLUTION HAS BEEN DETERMINED IT IS NECESSARY
C     TO CALCULATE THE SHADOW COSTS AND THE %ZIJ¤-CIJ¤,AND GREATER THAN ZERO
C     TO DETERMINE WHETHER THE SOLUTION IS OPTIMAL AND %ZIJ-CIJ¤,GREATER
C     THAN ZERO. IF NON-OPTIMAL THE NEW ELEMENT IS THE ONE WITH THE
C     LARGEST Z-C. IF OPTIMALITY EXISTS THE PROGRAM EXITS TO THE
C     OUTPUT ROUTINE.
 1211 DO 109 I#1,NORIG
```

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```
07/26/69          FORTRAIN                                    0003
      IU%I□#0
  109 IUI%I□#0
      DO 110 J#1,NDEST
      IV%J□#0
  110 IVI%J□#0
 1221 IUI%1□#1
      NROW#1
      NCOL#1
 1231 IF%IBAS%NROW,NCOL□-1□1232,1241,1241
 1241 IV%NCOL□#ICOST%NROW,NCOL□-IU%NROW□
       IVI%NCOL□#1
 1232 NCOL#NCOL&1
 1242 IF%NCOL-NDEST□1231,1231,1252
 1252 NROW#NROW&1
 1262 IF%NROW-NORIG□1272,1272,1261
 1272 IF%IUI%NROW□-1□1282,1252,1282
 1282 NCOL#1
 1292 IF%IBAS%NROW,NCOL□-1□1202,1263,1263
 1202 NCOL#NCOL&1
 1203 IF%NCOL-NDEST□1292,1292,1252
 1263 IF%IVI%NCOL□□1273,1202,1273
 1273 IU%NROW□#ICOST%NROW,NCOL□-IV%NCOL□
      IUI%NROW□#1
 1283 NCOL#1
      GO TO 1231
 1261 NROW#1
 1271 IF%IUI%NROW□□1281,1282,1281
 1281 NROW#NROW&1
 1291 IF %NROW-NORIG□1271,1271,1213
 1213 ISAV#0
      NROW#1
 1223 NCOL#1
 1233 IF%IBAS%NROW,NCOL□-1□1234,1243,1243
 1243 NCOL#NCOL&1
 1253 IF%NCOL-NDEST□1233,1233,1254
 1254 NROW#NROW&1
 1264 IF%NROW-NORIG□1223,1223,1274
 1274 IF%ISAV□1311,1511,1311
 1234 ISI#IU%NROW□&IV%NCOL□-ICOST%NROW,NCOL□
 1244 IF%ISI-ISAV□1243,1243,1245
 1245 ISAV#ISI
      NROW1#NROW
      NCOL1#NCOL
      GO TO 1243
C        THIS SECTION IS ENTERED ON EVERY NON-OPTIMAL ITERATION IT FINDS
C     THIS LOOP IN THE MATRIX CONTAINING THE NEW ELEMENT AND ELEMENTS IN
C     THE CURRENT BASIS. IF NO LOOP EXISTS AN ERROR MESSAGE IS PRINTED.
 1311 K#%NORIG&NDEST□*2
      DO 111 I#1,K
  111 INET%I□#0
      DO 112 I#1,NORIG
  112 INET1%I□#0
      DO 113 I#1,NDEST
  113 INET2%I□#0
      I#1
```

15

```
07/26/69          FORTRAIN                                    0004
 1321 INET%I□#NROW1
      INET%I&1□#NCOL1
      NROW#NROW1
      NCOL#1
      I#I&2
 1331 IF%IBAS%NROW,NCOL□-1□1332,1341,1341
 1341 IF%NCOL-NCOL1□1351,1332,1351
 1351 INET%I□#NROW
      INET%I&1□#NCOL
      I#I&2
      GO TO 1313
 1332 NCOL#NCOL&1
 1322 IF%NCOL-NDEST□1331,1331,1312
 1312 I#1
      WRITE%NPR,3□I,NROW1,NCOL1
    3 FORMAT%14H ERROR NUMBER,I4,I6,I6□
      GO TO 1511
 1313 INET2%NCOL□#1
      NROW#1
 1323 IF%IBAS%NROW,NCOL□-1□1333,1324,1324
 1333 NROW#NROW&1
 1343 IF%NROW-NORIG□1323,1323,1353
 1353 I#I-2
 1363 IF%I□1319,1319,1373
 1373 NROW#INET%I□
      NCOL#INET%I&1□
      INET2%NCOL□#0
       GO TO 1375
 1319 I#2
      WRITE%NPR,3□I,NROW1,NCOL1
      GO TO 1511
 1324 IF%NROW-INET%I-2□□1334,1333,1334
 1334 IF%INET1%NROW□□1353,1344,1353
 1344 INET%I□#NROW
      INET%I&1□#NCOL
      I#I&2
 1354 IF%NROW-NROW1□1364,1355,1364
 1355 I#I-2
      GO TO 1355
 1364 INET1%NROW□#1
      NCOL#1
 1374 IF%IBAS%NROW,NCOL□-1□1375,1384,1384
 1375 NCOL#NCOL&1
 1365 IF%NCOL-NDEST□1374,1374,1371
 1384 IF%NCOL-INET%I-1□□1394,1375,1394
 1394 IF%INET2%NCOL□□1371,1395,1371
 1395 INET%I□#NROW
      INET%I&1□#NCOL
      I#I&2
 1305 IF%NCOL-NCOL1□1313,1411,1313
 1371 I#I-2
 1381 IF%I□1319,1319,1382
 1382 NROW#INET%I□
      NCOL#INET%I&1□
      INET1%NROW□#0
```

```
07/26/68              FORTMAIN                                              0005
      GO TO 1333
C     AT THIS TIME WE HAVE FOUND A VALID LOOP IN WHICH ALL MOVES ARE
C     ORTHOGONAL AND SHALL NOW FIND THE SMALLEST ELEMENT IN THE LOOP
C     WHICH IS REACHED IN AN ODD NUMBER OR MOVES FROM THE ENTERING
C     ELEMENT. THIS IS THE ELEMENT WHICH WILL LEAVE.
 1411 I=3
      ISAV=K2
 1421 NROW=INET(I)
      NCOL=INET(I+1)
 1431 IF(IBAS(NROW,NCOL)-ISAV)1432,1441,1441
 1432 ISAV=IBAS(NROW,NCOL)
      NROW2=NROW
      NCOL2=NCOL
 1441 IF(NCOL-NCOL1)1451,1442,1451
 1451 I=I+4
 1461 IF(I-K)1421,1421,1471
 1471 I=3
      WRITE(NPR,3)I,NROW1,NCOL1
      GO TO 1511
 1442 IF(ISAV-K2)1443,1452,1452
 1452 I=4
      WRITE(NPR,3)I,NROW1,NCOL1
      GO TO 1511
 1443 J=-1
      NROW=INET(1)
      NCOL=INET(2)
      IBAS(NROW,NCOL)=ISAV
      ISAV=ISAV-K1
      I=3
 1444 NROW=INET(I)
      NCOL=INET(I+1)
 1453 IF(NROW-NROW2)1463,1454,1463
 1454 IF(NCOL-NCOL2)1463,1455,1463
 1455 IBAS(NROW,NCOL)=0
      GO TO 1473
 1463 IBAS(NROW,NCOL)=IBAS(NROW,NCOL)+J*ISAV
 1473 J=-J
      I=I+2
 1483 IF(NCOL-NCOL1)1444,1711,1444
C     THE NEXT ROUTINE IS THE OUTPUT ROUTINE. IT SI REACHED EITHER WHEN
C     AN OPTIMUM SOLUTION IS FOUND OR WHEN AN ERROR OCCURS AND THE OUTPUT
C     MAYBE OF INTEREST. IN CASE OF AN ERROR THE SHADOW PRICES REPRESENT
C     COORDINATES OF THE BASIS LOOP CALCULATIONS
 1511 WRITE(NPR,4)
      WRITE(NP,4)
    4 FORMAT(1H1,22HORIGIN    SHADOW PRICE)
    5 FORMAT(1H ,I6,I14)
 1521 WRITE(NPR,5)(I,IU(I),I=1,NORIGIN)
      WRITE(NP,5)(I,IU(I),I=1,NORIGIN)
 1531 WRITE(NPR,6)
      WRITE(NP,6)
    6 FORMAT(23H1DESTIN    SHADOW PRICE)
 1541 WRITE(NPR,5)(J,IV(J),J=1,NDESTIN)
      WRITE(NP,5)(J,IV(J),J=1,NDESTIN)
 1551 WRITE(NPR,7)
```

17

```
07/26/68              FORTMAIN                                              0006
      WRITE(NP,7)
    7 FORMAT(49H1ORIGIN  DESTIN  QUANTITY   UNIT COST TOTAL COST)
      II19=0
 1561 DO 114 I=1,NORIGI
      DO 114 J=1,NDESTI
      IF(IBAS(I,J)-K1)114,115,115
  115 ITEM=IBAS(I,J)-K1
      ITEM1=ICOST(I,J)
      ITEM2=ITEM*ITEM1
      WRITE(NPR,8)I,J,ITEM,ITEM1,ITEM2
      WRITE(NP,8)I,J,ITEM,ITEM1,ITEM2
    8 FORMAT(1H ,I6,I9,I12,I12,I12)
  114 CONTINUE
 1571 WRITE(NPR,7)
      WRITE(NP,7)
 1581 DO 116 J=1,NDESTI
      DO 116 I=1,NORIGI
      IF(IBAS(I,J)-K1)116,117,117
  117 ITEM=IBAS(I,J)-K1
      ITEM1=ICOST(I,J)
      ITEM2=ITEM*ITEM1
      WRITE(NPR,8)I,J,ITEM,ITEM1,ITEM2
      WRITE(NP,8)I,J,ITEM,ITEM1,ITEM2
      II19=II19+ITEM2
  116 CONTINUE
      WRITE(3,9999)II19
 9999 FORMAT(2 X,8TOTAL COST=2,I9)
      END
```

```
                                            [illegible]

SYMBOL   LOCATION      SYMBOL   LOCATION      SYMBOL   LOCATION      SYMBOL   LOCATION      SYMBOL   LOCATION
IBAS         0000      ICOST        0B40      FW           1A00      IV           1A60      IUL          1A70
IVS          1A50      ICRIG        1A70      IDEST        1C50      INET         1A80      INETL        1A90
UNETZ        1C90

                                            SCALARS

SYMBOL   LOCATION      SYMBOL   LOCATION      SYMBOL   LOCATION      SYMBOL   LOCATION      SYMBOL   LOCATION
NR           0234      NP           0238      NPR          023C      NORIG        0240      NDEST        0244
K1           0248      K2           024C      NDESTL       0250      NCRIGL       0254      NROW         0258
I            025C      NCOL         0260      J            0264      ISUMD        0268      ISUMO        026C
ISAV         0270      NROWL        0274      ISL          0278      NCOLL        027C      K            0280
NROW2        0284      NCOL2        0288      ISL9         028C      ITER         0290      ITERL        0294
ITER2        0298

                                       CALLED SUBROUTINES

IJTACOM     IJTAIXI

LABEL    LOCATION      LABEL    LOCATION      LABEL    LOCATION      LABEL    LOCATION      LABEL    LOCATION
01111        007C      00001        009C      01121        0040      01131        00D4      01141        0124
01151        0170      00101        0160      01161        01C6      00002        0248      01171        0254
00102        026C      00103        0260      01181        02CC      01191        0282      01101        03D6
00104        030E      01119        0346      01125        0368      00105        0372      01112        0360
00106        0384      01122        03F8      00107        0418      00108        0448      01142        0478
01143        049C      01133        0448      01192        0468      01162        04D4      01163        0506
01114        0530      01126        0542      01173        0594      01183        0588      01193        0614
01103        0630      01102        0656      01176        0672      01184        0640      01194        0680
01104        06C4      01165        070C      01211        0718      00109        0734      00110        0774
01271        07D8      01251        0748      01241        07D0      01232        0808      01242        081A
01252        0824      01262        0836      01272        0846      01282        0862      01292        0894
01202        0894      01203        0948      01263        0886      01275        08C0      01283        0902
01301        0914      01271        0922      01281        0936      01291        0946      01213        0994
01223        09A0      01233        0968      01243        0998      01293        09A0      01294        09DA
01204        09C0      01274        09D0      01234        09E2      01260        0A1C      01345        0A2C
01311        0A4A      00111        0A04      00112        0A94      00113        0AC4      01321        0AF6
01331        0B28      01341        0B52      01351        0B62      01332        0B90      01322        0B9C
01312        0BAC      00003        0BE0      01313        0C04      01323        0C20      01333        0C4A
01343        0C56      01353        0C64      01363        0C72      01373        0C78      01315        0CA0
01324        0CEA      01334        0D06      01344        0D1E      01354        0D46      01395        0D56
01304        0D60      01374        0D84      01375        0DAE      01369        0DBA      01304        0D80
01394        0DEC      01395        0E04      01305        0E2C      01371        0E42      01391        0E48
01302        0E5A      01411        0E8C      01421        0E9C      01431        0EB0      01432        0E82
01441        0F14      01451        0F24      01461        0F30      01471        0F40      01462        0F76
01452        0F8A      01443        0FC6      01444        101A      01493        1036      01494        1046
01459        1056      01463        1078      01473        1040      01483        108E      01511        10D4
00004        10F0      00005        111C      01521        112C      01531        11C4      00006        11E4
01541        1206      01591        1260      00007        12C0      01561        1304      00115        1338
00008        13EC      00114        1402      01571        1426      01581        1450      00117        1486
00116        1544      09999        1508
            COMPILATION COMPLETE     AMOUNT OF COMMON 007272      AMOUNT OF CORE 006208      ADDRESS BASE TABLE      1570
```

19

```
JOB  TRANS     07/26/68   DISK LINKAGE EDITOR DIAGNOSTIC OF INPUT

ACTION TAKEN   MAP
LIST   AUTOLINK   IJTACOM
LIST   AUTOLINK   IJTACOM
LIST   AUTOLINK   IJTAIXI
LIST   AUTOLINK   IJTFIOS
LIST   ENTRY
```

```
07/26/68  PHASE  XFR-AD  LOCORE  HICORE  DSK-AD   ESD TYPE   LABEL      LOADED  REL-FR
COMMON                                            COM                   001B00  001C60
         PHASE***  003540  003540  0069CF  3E 5 2   CSECT      FORTMAIN   003540  003540

                                                  CSECT      IJTACOM    004D30  004D00
                                                     ENTRY   IJTSAVE    0052CC

                                                  CSECT      IJTAIXI    005F28  005F28

                                                  CSECT      IJTACOM    0055E0  0055E0
                                                  *  ENTRY   FCVPI      0055E0
                                                  *  ENTRY   FCVPO      0055E4
                                                  *  ENTRY   FCVEI      0055E8
                                                  *  ENTRY   FCVEO      0055EC
                                                  *  ENTRY   FCVII      0055F0
                                                  *  ENTRY   FCVIO      0055F6
                                                  *  ENTRY   FCVOI      005788
                                                  *  ENTRY   FCVOO      005978

                                                  CSECT      IJTFIOS    005FC8  005FC8
                                                     ENTRY   UNITABE    0067F6
                                                  *  ENTRY   DOIOBASE   006602
                                                  *  ENTRY   GETUNIT    006378
                                                  *  ENTRY   OPENUNE    0063C6
                                                  *  ENTRY   SETLGUF    00648C
                                                  *  ENTRY   CCWNDIE    006798
                                                  *  ENTRY   DSKNTHS    0066A0
                                                  *  ENTRY   ASNJUPE    006834
                                                  *  ENTRY   FILTABE    006728
                                                     ENTRY   IJJCPDIN   005FC8
                                                  *  ENTRY   BUFINNT    006948
```

21

```
ORIGIN   SHADOW PRICE
     1              0
     2            100
     3            170
     4            113
     5            263
     6             26
     7            113
     8            113
     9            270
    10            179
    11            237
    12            207
    13            302
    14            306
    15            263
    16            226
    17            278
    18            263
    19            278
    20            348
    21            348
    22            235
    23            130
    24            330
    25            326
    26            311
    27            319
    28            309
    29            282
    30            219
    31            147
    32            190
    33            263
    34            198
    35            100
    36            196
    37            194
    38            126
    39            194
    40            194
    41            196
    42            122
    43            222
    44            260
    45            277
    46            296
    47            166
    48            267
    49            219
    50            285
    51            193
    52            219
    53            217
    54            235
    55            235
    56            106
    57            128
    58            305
    59              6
    60            109
    61            -11
```

```
 64      83
 65     141
 66     276
 67      92
 68      92
 69     117
 70     350
 71     200
 72      92
 73      92
 74      92
 75      -3
 76     269
 77     223
 78     163
 79     173
 80     253
 81     260
 82      83
 83     305
 84     150
 85     130
 86     190
 87     267
 88     252
 89     344
 90     282
 91     196
 92     416
 93     303
 94      89
 95     414
 96     394
 97     244
 98     134
 99     190
100     232
101     267
102     164
103     250
104     206
105     206
106     184
107     296
108     331
109     276
110     271
111     271
112     271
113     271
114     144
115     272
116     272
117     216
118     297
119     364
```

23

```
DESTIN    SHADOW PRICE
     1          1594
     2          1656
     3          1670
     4          1672
     5          2586
```

ORIGIN	DESTIN	QUANTITY	UNIT COST	TOTAL COST
1	3	400	1676	670400
2	3	600	1776	1065600
3	3	300	1846	553800
4	3	28	1789	50092
5	3	95	1939	184205
6	3	96	1702	163392
7	3	40	1789	71560
8	3	40	1789	71560
9	1	160	1932	309120
10	1	200	1729	345800
11	3	230	1913	439990
12	3	280	1883	527240
13	3	220	1978	435160
14	3	200	1982	396400
15	3	20	1939	38780
16	3	49	1900	93100
17	3	56	1956	109536
18	3	59	1939	114401
19	3	110	1954	214940
20	3	66	2024	133584
21	3	46	2024	93104
22	1	48	1789	85872
23	4	210	1802	378420
24	3	250	2006	501500
25	3	250	2002	500500
26	3	130	1987	258310
27	3	220	1995	438900
28	1	64	1939	124096
29	4	35	1874	65590
30	2	50	1891	94550
31	4	25	1819	45475
32	3	63	1866	117558
33	3	30	1939	58170
34	3	39	1874	73086
35	3	30	1856	55680
36	4	35	1866	65310
37	4	37	1866	69042
38	4	20	1796	35920
39	4	25	1866	46650
40	4	33	1866	61578
41	4	25	1866	46650
42	1	1130	1676	1893880
43	1	240	1776	426240
44	1	189	1822	344358
44	2	159	1924	305916
45	1	200	1831	366200
46	1	181	1850	334850
46	3	99	1972	195228
47	3	430	1842	792060
48	3	130	1943	252590
49	1	19	1789	33991
50	1	50	1839	91950
51	3	45	1871	84195
52	1	40	1789	71560
53	1	34	1766	60044
54	1	31	1789	55459
55	2	85	1891	160735
56	1	41	1660	68060
57	3	85	1904	161840
58	2	115	2041	234715
59	4	150	1676	251400
60	4	500	1776	888000
61	4	290	1661	481690
62	4	410	1761	722010
63	4	210	1755	368550
64	4	210	1755	368550
65	4	210	1813	380730
66	1	200	1830	366000
67	4	35	1764	61740
68	4	25	1764	44100
69	4	50	1789	89450
70	1	59	1904	112336
71	1	54	1834	99036
72	4	30	1764	52920
73	4	50	1764	88200
74	4	52	1764	91728
75	4	75	1669	125175
76	4	44	1941	85404
77	4	300	1895	568500
78	4	300	1835	550500
79	4	300	1845	553500
80	4	150	1924	288600
81	4	130	2032	264160
82	4	270	1755	473850
83	4	150	1977	296550
84	4	210	1858	390180
85	4	180	1810	325800
86	4	150	1860	279000
87	4	24	1939	46536
88	4	125	1874	234250
89	4	22	2016	44352
90	4	90	1874	168660
91	4	37	1866	69042
92	4	25	2086	52150
92	5	50	3000	150000
93	4	120	1874	224880
94	4	150	1761	264150
95	5	150	3000	450000
96	3	150	2070	310500
97	4	250	1916	479000
98	4	250	1806	451500
99	4	50	1831	91550
100	4	63	1904	119952
101	4	63	1939	122157
102	4	60	1836	110160
103	4	180	1922	345960
104	2	125	1942	242750
105	2	187	1942	363154
106	2	500	1840	920000
107	2	325	1950	633750
108	2	188	1987	373556
109	2	57	1930	110010
110	2	35	1927	67445
111	2	29	1927	55883
112	2	35	1927	67445
113	2	25	1927	48175
114	2	1352	1800	2433600
115	2	20	1928	38560
116	2	10	1928	19280
117	3	166	1892	314072
118	2	229	1953	447237
118	4	25	1969	49225
119	2	66	2020	133320

25

```
 ORIGIN   DESTIN  QUANTITY    UNIT COST TOTAL COST
      9        1       160         1932     309120
     10        1       200         1729     345800
     27        1        48         1789      85872
     28        1        64         1939     124096
     42        1      1130         1676    1893880
     43        1       240         1776     426240
     44        1       189         1822     344358
     45        1       200         1831     366200
     46        1       181         1850     334850
     49        1        19         1789      33991
     50        1        50         1839      91950
     52        1        40         1789      71560
     53        1        34         1786      60724
     54        1        31         1789      55459
     56        1        41         1660      68060
     66        1       200         1830     366000
     70        1        59         1904     112336
     71        1        54         1834      99036
     30        2        50         1891      94550
     44        2       159         1924     305916
     55        2        85         1891     160735
     58        2       115         2041     234715
    104        2       125         1942     242750
    105        2       187         1942     363154
    106        2       500         1840     920000
    107        2       325         1950     633750
    108        2       188         1987     373556
    109        2        57         1930     110010
    110        2        35         1927      67445
    111        2        29         1927      55883
    112        2        35         1927      67445
    113        2        25         1927      48175
    114        2      1352         1800    2433600
    115        2        20         1928      38560
    116        2        10         1928      19280
    118        2       229         1953     447237
    119        2        66         2020     133320
      1        3       400         1676     670400
      2        3       600         1776    1065600
      3        3       300         1846     553800
      4        3        28         1789      50092
      5        3        95         1939     184205
      6        3        96         1702     163392
      7        3        40         1789      71560
      8        3        40         1789      71560
     11        3       230         1913     439990
     12        3       280         1883     527240
     13        3       220         1978     435160
     14        3       200         1982     396400
     15        3        20         1939      38780
     16        3        49         1900      93100
     17        3        54         1954     105516
     18        3        59         1939     114401
     19        3       110         1954     214940
     20        3        66         2024     133584
     21        3        46         2024      93104
     24        3       250         2006     501500
     25        3       250         2002     500500
     26        3       130         1987     258310
     27        3       220         1995     438900
     32        3        63         1866     117558
     33        3        30         1939      58170
     34        3        39         1874      73086
     35        3        30         1856      55680
     46        3        99         1972     195228
     47        3       430         1842     792060
     48        3       130         1943     252590
     51        3        45         1871      84195
     57        3        85         1904     161840
     96        3       150         2070     310500
    117        3       166         1892     314072
     23        4       210         1802     378420
     29        4        35         1874      65590
     31        4        25         1819      45475
     36        4        35         1866      65310
     37        4        37         1866      69042
     38        4        20         1796      35920
     39        4        25         1866      46650
     40        4        33         1866      61578
     41        4        25         1866      46650
     59        4       150         1676     251400
     60        4       500         1776     888000
     61        4       290         1661     481690
     62        4       410         1761     722010
     63        4       210         1755     368550
     64        4       210         1755     368550
     65        4       210         1813     380730
     67        4        35         1764      61740
     68        4        25         1764      44100
     69        4        50         1789      89450
     72        4        30         1764      52920
     73        4        50         1764      88200
     74        4        52         1764      91728
     75        4        75         1669     125175
     76        4        44         1941      85404
     77        4       300         1895     568500
     78        4       300         1835     550500
     79        4       300         1845     553500
     80        4       150         1924     288600
     81        4       130         2032     264160
     82        4       270         1755     473850
     83        4       150         1977     296550
     84        4       210         1858     390180
     85        4       180         1810     325800
     86        4       150         1860     279000
     87        4        24         1939      46536
     88        4       125         1874     234250
     89        4        22         2016      44352
     90        4        90         1874     168660
     91        4        37         1866      69042
     92        4        25         2086      52150
     93        4       120         1874     224880
     94        4       150         1761     264150
     97        4       250         1916     479000
     98        4       250         1806     451500
     99        4        50         1831      91550
    100        4        63         1904     119952
    101        4        63         1939     122157
    102        4        60         1836     110160
    103        4       180         1922     345960
    110        4        25         1969      49225
     92        5        50         3600     180000
     95        5       150         3000     450000
TOTAL COST= 33094372
```

27

VIII. Sample Problem

The sample problem takes about five minutes to compile and execute including all output. In order to run place Deck I and Deck II behind the necessary IPL cards and run as a single job. The output is included with the program listing.

When using the program, it is suggested that row availabilities of 0 never be used, since this can cause some problems in the program. It would be advisable if instead of 0, a small number such as 1 be used which would not seriously effect the solution but would avoid certain problems in the program. The new deck with the program handles certain other problems which can occur on the program under certain conditions.

The flow-charts for the program were done on standard flow-charting sheets with preprinted block numbers. Unfortunately, the block numbers did not reproduce well, therefore, it is not obvious what blocks the letters and numbers refer to. They refer to the standard preprinted block letters on the sheets.

Corrected: July 68